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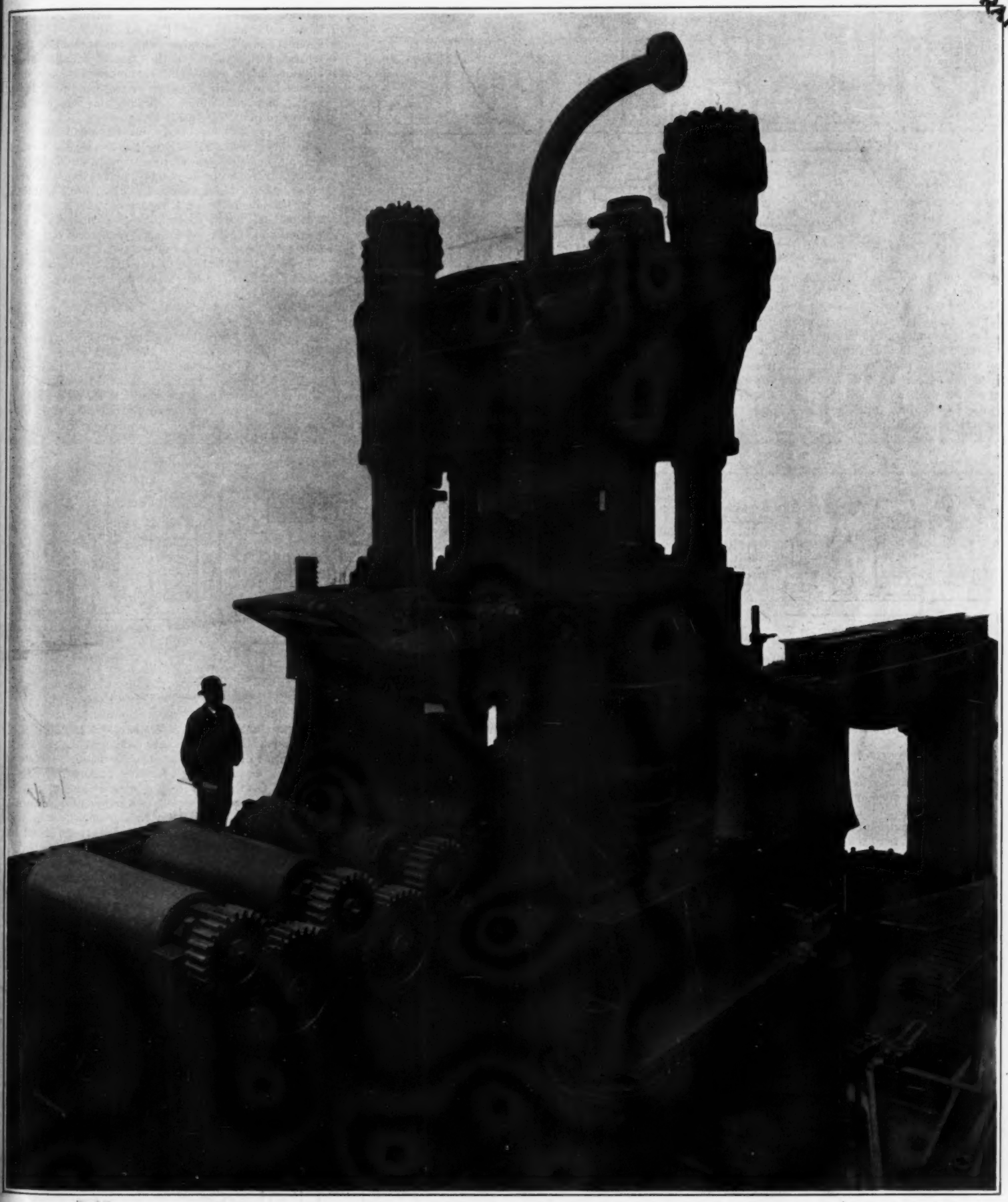

LARGE HYDRAULIC PLATE SHEARS BUILT IN SHEFFIELD, ENGLAND.—[See page 295.]

By-Products of the Modern Coke Oven*

Recovery of Gas, Ammonium Compounds, Benzol, Etc.

By C. A. Meissner

THE recovery of the by-products from the gases evolved in the coking process in a modern by-product coke oven plant—namely, gas, ammonia, sulphate of ammonia, and tar as well as benzol—is a very broad subject and I will try to confine myself as closely as possible to the points of main interest.

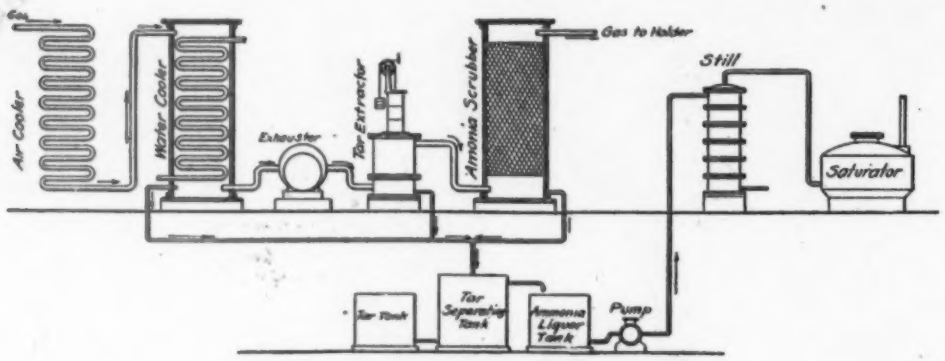

Fig. 1.—The indirect ammonium sulphate process.

Briefly, the gas as it leaves the ovens through the foul gas main, located above the ovens, is taken over to the by-product plant in large mains and ordinarily is there cooled, the tar extracted, naphthalene thrown down as far as possible, the ammonia is scrubbed out of the gas by passing it through water towers or other apparatus, weak ammonia liquor is distilled, the ammonia passed into lead-lined saturators containing sulphuric acid, and sulphate of ammonia is formed, or the distilled ammonia is placed in tanks and shipped as strong ammonia liquor. This is an outline of the *old indirect process.*

In the *direct recovery process* the scrubbing of ammonia from the gases is avoided by passing the gases through the saturator after the tar separation has been accomplished. In some of the so-called direct processes the tar is separated by cooling the gases and in this case a certain proportion of the ammonia is precipitated with the tar and must be distilled. In some of the direct processes the tar is separated without precipitation of the ammonia salts. These latter processes are, therefore, more preferably called direct than the processes where some of the ammonia is precipitated, which should be more properly called semi-direct.

There is also another process in which the sulphur contained in the gases is utilized, generally referred to as the "thiosulphate process," of which I will give later a brief but more detailed description.

We have, therefore, at present really four processes that are largely used all over the world for recovering by-products: namely, the *indirect*, the *semi-direct*, the *direct*, and the *thiosulphate*.

The effect of the coking time upon the recovery of by-products, particularly ammonia, is a subject that has not been fully worked out. Apparently the longer coking time increases the percentage of recovery of ammonia and the losses in ammonia become greater as we decrease the coking time up to a certain point. I doubt whether this point can at the present time be definitely settled upon, because there are other reasons for ammonia losses than the coking time itself. We have generally felt that with a short coking time we do not get as much of the total available ammonia as at plants having a longer coking time.

I understand that in Germany they recover up to 95 per cent of the total ammonia available in the coal. A factor that assists the Germans is that their coal is almost invariably washed and, therefore, contains a certain amount of moisture, which is effective in obtaining a larger percentage of the available ammonia.

So far as our experience has gone, we seem to have no material difference in our recovery percentage when running between 16½ and 20 hours coking time. We have practically no experience over any period of time on 24-hour coking time, excepting at Farrell, but there the conditions are to my mind not of such a nature as to be quite comparable to our conditions at the other plants. This subject is undergoing careful study at all our plants.

The same applies more or less to the question of whether a hot top of the oven is more likely to increase the loss of recoverable ammonia than a cooler top. The general impression so far has been that the cooler top is the better in this respect. Points like these have to be carefully balanced, because from them arises the question of what is more economical to produce, a good blast furnace coke or a larger by-product recovery. The object of the Steel Corporation has always been, and I think rightly so, to make a good furnace coke and then to recover as much of the by-products as is consistent with this. The money loss through inferior coke and its detrimental effect on blast furnace practice soon offsets any slight gain through increased ammonia yield at the coke oven.

THE INDIRECT PROCESS FOR RECOVERY OF AMMONIA.

In the indirect process (Fig. 1) the gas coming from the ovens is air- and water-cooled to allow the deposition of tar and combined ammonia liquor, and is then passed through scrubbers where the free ammonia contained in the gas is washed out by means of water. This weak ammonia water, together with the ammonia liquor separated from the tar, is then treated with steam and milk of lime in a still, and the ammonia vapors either passed into an acid saturator or else condensed into a strong ammonia liquor, depending on whether it is desired to produce sulphate or liquor.

KOPPERS' SEMI-DIRECT SULPHATE PROCESS.

In this process (Fig. 2) the gas leaving the ovens is first air- and water-cooled to a temperature of 104 deg. Fahr. This throws down most of the tar, the water vapor, the combined ammonia and some free ammonia.

The ammonia liquor is separated from the tar and treated in stills with steam and milk of lime in the usual way, the ammonia vapors being either converted into ammonia liquor or else returned to the system for conversion into sulphate, by entering the gas main at a point prior to the water coolers and traveling with the gas to the saturator.

The gas, after leaving the water coolers freed from most of the tar, passes through an exhauster to P. & A. tar extractors, where the remainder of the tar is removed. Thence the gas is returned to a heater where the temperature of the gas is raised to about 176 deg. Fahr., the heating medium being exhaust steam or the uncooled gas from the ovens, usually the former in the later plants.

The heated gas then passes into the saturator, where the ammonia in the gas is neutralized by the sulphuric acid with the formation of ammonium sulphate. Leaving the saturator at a temperature of about 120 deg. Fahr., the gas passes without further cooling to the gas holder for return to the ovens and its other uses.

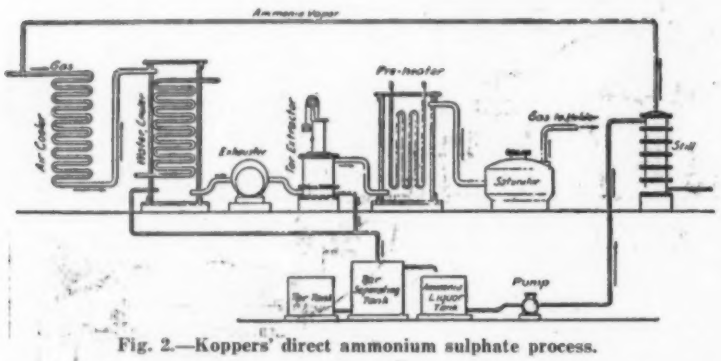

Fig. 2.—Koppers' direct ammonium sulphate process.

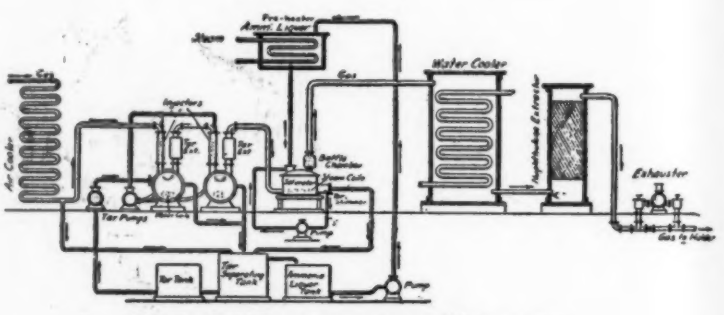

Fig. 3.—Otto direct ammonium sulphate process.

OTTO DIRECT SULPHATE PROCESS.

In the Otto direct sulphate process (Fig. 3) the gas from the ovens is air-cooled to a temperature of about 200 deg. Fahr. and is then further cooled to a temperature a little above the dew point of steam, about 160 deg. Fahr., by means of a tar spray.

The object of cooling to about the dew point is in order to prevent the deposition of ammonia liquor, which would occur if cooled to a lower temperature, and thus necessitate the use of stills as in the other processes. By keeping the temperature a little above the dew point this ammonia remains as vapor in the gas. Experience

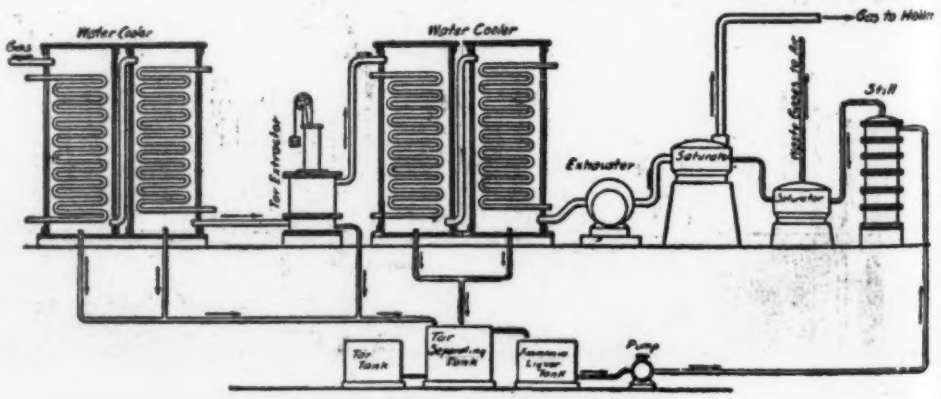

Fig. 4.—Collin semi-direct ammonium sulphate process.

*A part of a paper on "The Modern By-product Coke Oven," presented at the recent meeting of the American Iron and Steel Institute and published in the *Metallurgical and Chemical Engineer.*

has shown, however, that some ammonia is invariably thrown down with the tar.

The spraying with tar is performed by Koerting injectors in a two-compartment tar tank in series, so the gas is twice sprayed. The temperature of the spraying tar is kept at the right degrees by means of water-cooling pipes in the tank.

The surplus tar washed out of the gas overflows into a regular separating tank, where the ammonia liquor which has come down with the tar is removed. The amount of this liquor is small.

The tar-washed gas then passes through a stationary bell similar in function to a P. & A. tar extractor, where the last of the tar is supposed to be removed, but on account of the high temperature of the gas some tar continues to remain therein.

The gas then passes through a covered gas main to the saturators, where neutralization of the ammonia occurs with the formation of ammonium sulphate, which is ejected and dried in the usual way.

On account of imperfect separation of the tar from the gases, some tar is always deposited in the saturator; therefore, it is equipped with a lead dam and siphon to allow the top portion of the mother liquor to be withdrawn into an open top tank in which the tar is skimmed off and the mother liquor returned to the saturator.

On account of the gas entering the saturator being fairly well saturated with water vapor, which, if deposited here, would weaken the acid bath and prevent proper absorption of the ammonia, the saturators are equipped with steam coils made of lead, and the bath is kept heated by means of steam to a temperature high enough to insure the retention of the water vapor in the gas.

The ammonia liquor separated from the tar is heated by steam coils in a small tank and is then introduced direct into the saturator. After leaving the saturator, the gas enters a tank containing brick baffles to allow separation of the acid and thence to horizontal tubular water coolers, where the gas is cooled to separate the water and as much naphthalene as possible. At some places a further naphthalene extractor is being installed.

After leaving here, the gas is drawn through an exhauster and pumped to the gas holder, ovens, etc.

Temperatures taken at a representative plant at the various stages of the operation were as follows:

Entering Koerting injectors	200 deg. Fahr.
After spraying with tar	162 deg. Fahr.
Entering saturator	160 deg. Fahr.
Leaving saturator	185 deg. Fahr.
Entering water coolers	171 deg. Fahr.
Leaving water coolers	102 deg. Fahr.

THE COLLIN SEMI-DIRECT SULPHATE PROCESS.

In this process (Fig. 4) the gas from the ovens passes through the usual horizontal tubular water coolers where most of the tar and combined ammonia are separated, then through a P. & A. tar extractor where the remainder of the tar is separated. The cleaned gas then passes through another set of water coolers exactly similar to the first set, and then through the exhausters to the saturator.

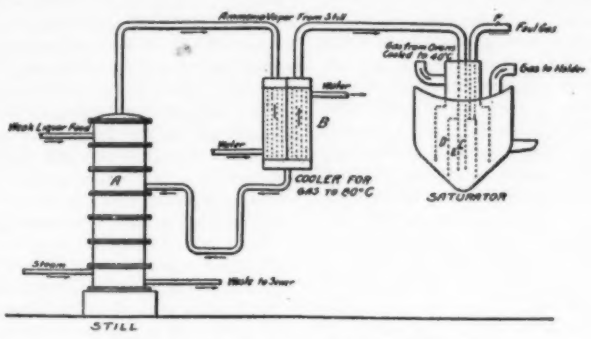

Fig. 5.—Collin direct sulphate process.

Two saturators in series are used in this process, set at different levels in the building.

The cleaned gas enters the upper saturator, the bath of which is kept at about 25 per cent free acid, and the liquor from this bath is used as the saturating medium in the second or lower saturator, into which pass the ammonia vapors from the stills which are used in this similarly as in the Koppers process.

One advantage claimed for this system of treating the ammonia in two saturators, one for the direct gas and the other for the still vapors, is that the "stink" gases (H_2S, CN, etc.) from the latter are at once eliminated from the system, escaping from the second saturator into the air and thus never coming into contact with the gas.

The temperatures at one plant where this process is in operation were as follows:

Gas entering first set of water coolers	212 deg. Fahr.
Gas entering the P. & A. tar extractor	113 deg. Fahr.
Gas leaving second set of water coolers	73 deg. Fahr.
Gas entering saturator	77 deg. Fahr.
Gas leaving saturator	100 deg. Fahr.

Experiments for a *modification of this process* are being conducted along the following lines:

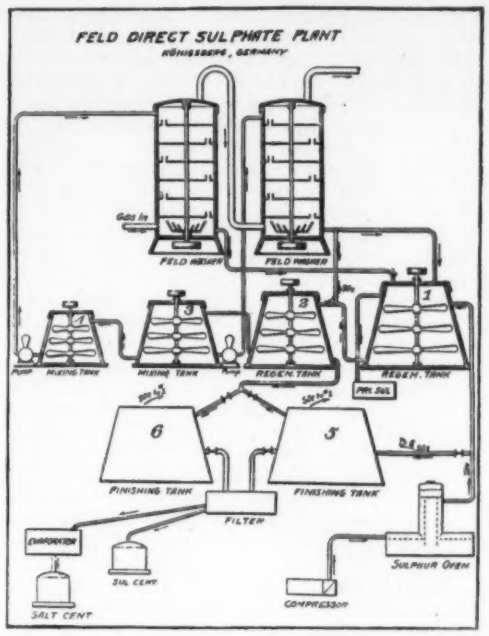

Fig. 6.—The Feld direct sulphate process.

into the saturator. The superheater will be heated either by combustion of surplus gas from the ovens, or by utilizing the waste heat from the chimney flues.

FELD DIRECT SULPHATE PROCESS.

In this process (Fig. 6) the sulphur in the coke oven gases is utilized to produce most of the sulphuric acid required for the neutralization of the ammonia in these gases. After leaving the ovens, the gases pass through the usual coolers, exhausters and tar extractors, and are then washed with a solution of ammonium polythionate, which absorbs the ammonia from the gases, forming

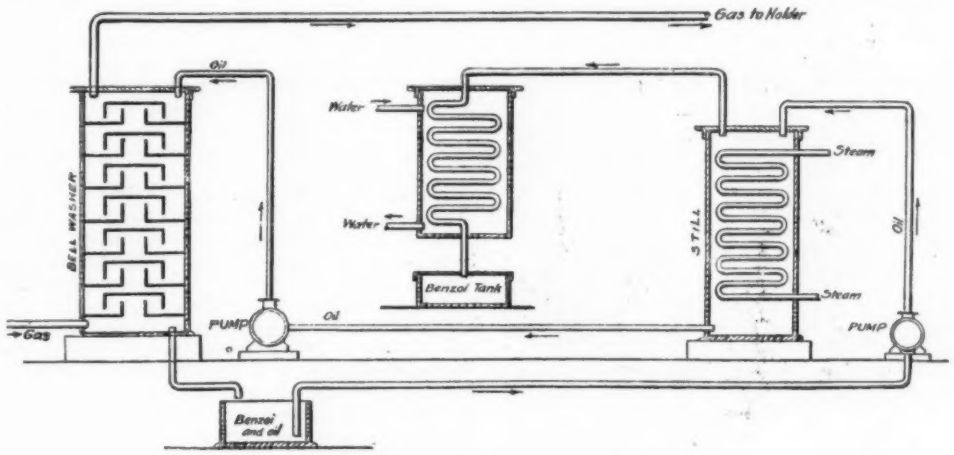

Fig. 7.—Apparatus for recovery of Benzol.

The gas from the ovens will be treated in one set of horizontal coolers, P. & A. tar extractors, and another set of horizontal coolers as above described.

In the first set of coolers, however, the ammonia liquor will be used for cooling instead of water. The ammonia liquor will thus become heated to a temperature of about 194 deg. Fahr. in its action of cooling the hot gases from the ovens.

This preheated liquor, and any vapor which may be evolved, will be run to a superheater and brought to a temperature of about 300 deg. Fahr., which is considered sufficient to decompose the compounds of ammonia (chloride, carbonate, etc.).

The ammonia vapor evolved passes from here directly

ammonium thiosulphate and precipitating sulphur according to this reaction.:

$$(NH_4)_2S_4O_6 + 2NH_3 + H_2S = 2(NH_4)_2S_2O_3 + S.$$

This mixed solution and precipitate is treated in a tank provided with mechanical stirrers with sulphur dioxide formed by burning in a suitable oven some of the sulphu previously precipitated; the thiosulphate is thereby regenerated to ammonium polythionate, according to the following reaction, and the precipitated sulphur is removed:

$$2(HN_4)_2S_2O_3 + 3SO_2 + S = 2(NH_4)_2S_4O_6S.$$

When the oxidation is complete, the solution of polythionate is heated with exhaust steam or otherwise to a temperature of 60 deg. Cent. to 70 deg. Cent. until

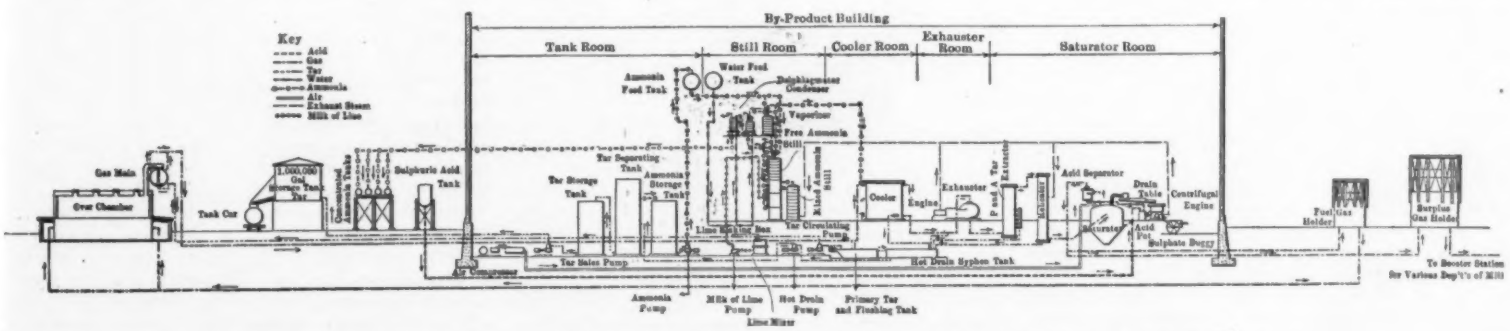

Fig. 8.—Diagrammatic sketch of flow of gases, extraction of various by-products, etc., in a by-product coke oven plant.

all the ammonium polythionate is decomposed into ammonium sulphate, sulphur dioxide, and sulphur. The sulphur dioxide is used for further regeneration, the sulphur is filtered off, and the solution of ammonium sulphate is evaporated until the salt crystallizes out:

$$(NH_4)_2S_4O_6 + \text{Heat} = (NH_4)_2SO_4 + SO_2 + 2S.$$

RECOVERY OF BENZOL.

Benzol is defined as a colorless, inflammable liquid compound having the chemical formula C_6H_6.

Benzol is recovered from coke oven gases by scrubbing them with light oil, in washers of various types, after the ammonia has been separated from the gases; that is, after the gases leave the ammonia scrubbers in the indirect process, or after the gases issue from the saturator in the direct process. Some benzol is also precipitated with the tar.

The oil used for scrubbing is usually in this country a light oil of specific gravity about 0.8; it should be neither too thin, in which case long enough contact with the gas is not obtained, nor too thick, in which case there is a tendency to solidify.

After scrubbing, the mixture of washing-oil and benzol is conveyed to a still, where the benzol is driven off, with steam as the heating medium. The benzol so obtained is designated as "crude" benzol and contains about 50 per cent benzol. This is either shipped as such, or is purified by further distillation to various grades of benzol or fractionally distilled with separation of toluol and xylol when required. The oil used for scrubbing is used over and over again until it gradually becomes too thick by accumulation of naphthalene and tar.

The yield of benzol depends largely on the volatile contents of the coal; usually the higher the volatile matter the higher is the yield of benzol.

USES OF BY-PRODUCTS.

Tar.—This is used largely for two purposes, namely, distillation for production of creosote and light oils and pitch, and for use in road making. Both of these uses of tar have increased very greatly in the last few years and the tendency for still further increase indicates a very large proportion of the future production will be similarly used. Tar is further being used successfully in open-hearth furnaces, replacing producer-gas; also in heavy oil engines, provided it does not contain too much free carbon. It has also been burnt with success under boilers through specially devised burners.

Ammonia and Ammonium Sulphate.—The ammonia in the form of concentrated ammonia liquor is used in making anhydrous and aqua ammonia for refrigeration, and other purposes, in the production of soda ash, explosives, and in other lines of chemical manufacture. Sulphate of ammonia is very largely used as a fertilizer, although in some cases it is converted to ammonium hydrate for use in chemical manufacture. When used as a fertilizer it is usually mixed in definite proportions with other fertilizer ingredients, such as acid phosphate, potash, etc., according to the conditions.

Coke Dust and Coke Breeze.—The coke dust is used to advantage in the steel mills in soaking pits, etc. Coke dust up to ¼ inch in size can also very profitably be burnt in specially designed grates under boilers. The coke breeze is sold for domestic purposes, having been screened and sometimes sized. In locations where coal is cheap the disposal of the coke breeze may at times be somewhat troublesome.

Surplus Gas.—The surplus gas obtained from the coke ovens, which has a value of 400 to 650 B.t.u. per cubic foot, depending on the coal used, is one of the most valuable by-products. It can be used for all sorts of heating purposes at the steel plant and its value in replacing coal for all purposes at one of our steel plants is equivalent to approximately one half million net tons of coal per year, based on 40,500 cubic feet of surplus gas being equivalent to one net ton of coal at that point.

This surplus gas is also used for illuminating purposes and can be piped long distances for this purpose. In Europe it is used quite extensively in gas engines. Experiments have also been made using it in the open hearth furnaces alone or mixed with blast-furnace gas, the latter method having been largely adopted in certain parts of Europe and I believe ultimately in this country will receive due consideration.

Benzol.—The principal uses of benzol and its products are:

(1) As a motor fuel.
(2) To enrich the illuminating power of gas.
(3) In manufacture of aniline dyes.
(4) As a solvent for rubber and similar substances.
(5) In manufacture of gunpowder.

Production of benzol in Europe has increased enormously in recent years due to its increasing consumption as a motor fuel in place of gasoline. At the same time the price has steadily increased, more than keeping pace with the increased production.

Solving the Fuel Problem for the Motor Truck*

Characteristics of Kerosene as a Fuel for Internal Combustion Engines

By Harold Whiting Slauson

No sooner has the gasoline motor been well-nigh perfected, than the automobile designers and drivers find themselves face to face with another problem. Methods of carburetion, lubrication, and ignition have all been successfully developed, and the driver now looks for little trouble from these sources; but the success of the designers in eliminating these troubles has, in a sense, defeated its own purpose, for when the low price, reliability, and compactness of the gasoline engine began to solve so many power-producing problems, the demand for what had once been the "useless by-product" of the refineries increased to such an extent that gasoline is now a valuable fuel. A fifty per cent increase in price in a few months is not so important in itself, but when it is taken as an indication of further increases the problem assumes a serious aspect, serious for the motor truck owner, at least, if not for the driver of a pleasure car.

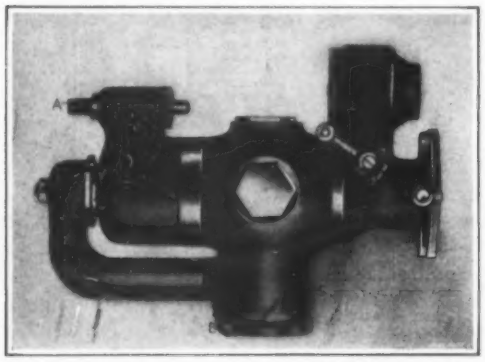

Fig. 1.—Kerosene carbureter in which the primary air is admitted cold and the exhaust heat is used only around the float chamber.

The reason for the slow acceptance of substitutes for gasoline is psychological as well as chemical and mechanical. The owner of a pleasure car is not as disturbed over the few cents increase in the cost of gasoline as might be expected; he argues that gasoline is a tested fuel that has given satisfaction, and he understands its characteristics perfectly. A small or even a large amount, spilled when filling the tank, causes no damage or annoyance, for the evaporation is rapid and no residue is left to collect dust. The heavier oils, such as kerosene, however, are slow to disappear by evaporation. The owner of a motor truck, however, has invested in the machine because he is convinced it will represent a dollars-and-cents saving over his former delivery or hauling system, and any device which will contribute toward economical operation will be given due consideration; furthermore, the fuel consumption of a motor truck is much higher than that of a pleasure car. A gallon of gasoline that will drive the latter twelve or fifteen miles will serve only for one third or one fourth that distance in a two- or three-ton business vehicle.

KEROSENE AS A FUEL FOR INTERNAL COMBUSTION ENGINES.

In the search for new fuels that has been in progress since it has been evident that the supply of gasoline could not hold out, kerosene has stood foremost. This is logically due to several reasons, the chief of which is probably the fact that no change whatsoever need be made in the design of the gasoline engine in order to adopt it to the use of kerosene. In addition, kerosene is but one group lower than gasoline in the great hydrocarbon family of which petroleum is the parent, and the motor car driver therefore feels that he is not dealing with an absolutely new and unknown fuel; but of course, kerosene would not be regarded as a satisfactory solution of the fuel problem were it not present in large quantities in all grades of petroleum. The most valuable petroleum is the Pennsylvania crude, but even in this, gasoline is not present to a greater extent than three or four per cent, and in the poorer qualities, it is so scarce that no effort is made to distill it. Kerosene, on the other hand, is present in varying quantities in practically every quality of petroleum and in some grades comprises as much as thirty or forty per cent of the total. Hence, the supply of kerosene would seem to answer the fuel requirements of the internal combustion engines for years to come, or at least until the engines manufactured and in use to-day are worn out and the condition of the alcohol market has been so changed that the production of alcohol-burning motors becomes profitable.

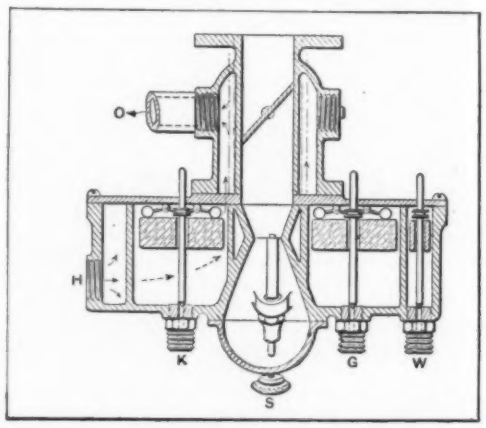

Fig. 2.—Kerosene carbureter having part of intake pipe and throttle chamber jacketed for heating, as well as the float chamber.

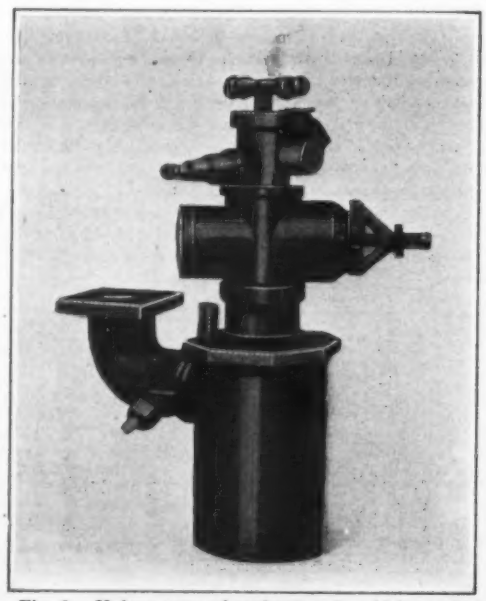

Fig. 3.—Unique type of carbureter in which spark plug maintains a continuous flame in path of atomized kerosene.

When we say that the specific gravity of present-day gasoline on the Baûme scale is approximately 62 and that of kerosene 45 or 48, we do not express the only difference that exists between the two liquids. Kerosene has a higher specific gravity and is, therefore, heavier and less volatile than gasoline, but it is by no means a poor substitute. The carbon content is different, and therefore kerosene in a gaseous state is as dissimilar from gasoline as when in a liquid form. Both before and after evaporation, the two fuels must be treated differently. The fact that kerosene is not volatile at ordinary atmospheric temperatures was the first problem to be met by the designers. It must be borne in mind that it is the *vapor* of the fuel, and not small globules, that must be mixed with the proper quantity of air and ignited in the cylinder of the internal combustion engine. A spray is not a vapor; the former may be mixed with the air but the liquid will separate and condense as soon as it strikes the cylinder walls.

* Reproduced from *Machinery*.

Engines of the Diesel type inject either kerosene or crude oil into the cylinder in the form of a spray, but previous to ignition, the compression is increased to 500 pounds per square inch, or more, which generates sufficient heat to gasify the fuel particles immediately and ignite them. The compression of the gasoline motor, however, does not exceed 70 or 80 pounds per square inch, and this is insufficient to enable the engine, when cold, to vaporize the non-volatile particles that may be introduced into it in the form of the finely divided spray. A gasoline engine will become hot in a very few minutes of operation, and this appealed to the designers as a convenient source of heat for increasing the temperature of the liquid kerosene to the evaporating point; therefore, three fourths of all the kerosene carbureters used at the present time employ a bowl or float chamber to contain a small quantity of the liquid, and this is surrounded by a jacket that communicates with the exhaust pipe of the motor. A carbureter of this type is shown in Fig. 1. The fuel inlet is at *A* and the exhaust heat is admitted at *B*. The motor is started on a small amount of gasoline, and when the exhaust pipe has become sufficiently hot to vaporize the kerosene in the bowl, a two-way valve is turned which conducts the heavier fuel to the carbureter. The same carbureter is used for both the gasoline and the kerosene, although with some designs the gasoline is burned directly around the bowl containing the kerosene, to obtain the necessary heat.

Simple as such carbureters may appear, there are a number of problems that must be solved before the

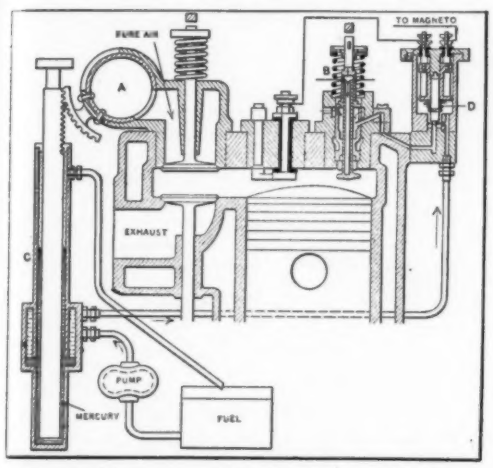

Fig. 4.—Kerosene carbureting device which requires no heat. It is equipped with electrically operated valve for controlling supply of fuel.

use of kerosene can give as good results as are obtained from gasoline. The fineness into which the kerosene jet should be divided, the amount of heat to which the fuel should be subjected, and the treatment of the mixture in order that the same "flexibility" as that delivered by a gasoline engine can be obtained from one using kerosene, are all subjects of vital interest to the designer and user. It has been found that the finer the spray into which the kerosene jet is divided, the more complete the combustion in the engine cylinder; atomization or pulverization probably more correctly describes the process to which the fuel should be subjected. The proper pulverization of the fuel, together with the application of heat, breaks it up into so fine a mist that actual gasification is not necessary, provided the intake manifold is made of such a shape and dimensions that the velocity of the mixture is kept high, to prevent condensation on the cool walls of the pipe. The temperature to which the fuel is raised before atomization is generally from 200 to 300 degrees, although in some carbureters the kerosene is subjected to a temperature of 600 degrees.

One of the drawbacks to the more general use of kerosene in automobiles has been its reputation for forming heavy deposits of carbon in the cylinder. When this condition exists, however, it is an indication of improper pulverization, condensation, or of faulty design or adjustment of the heat- and air-regulating apparatus. The best lubricating oils should be used when kerosene is employed as a fuel, but the formation of carbon in the cylinders or the presence of black smoke at the exhaust indicates that imperfect combustion is taking place.

CARBURETER IN WHICH VARIABLE QUANTITY OF WATER IS ADDED TO KEROSENE MIXTURE.

An elaboration of the general type of kerosene carbureter previously referred to has been in successful use on many of the large traction engines used in the western section of this country. In this carbureter, cold air is supplied to the fuel immediately after pulverization, for it was found that this arrangement gave the greatest power and the best economy. It was also discovered that if the air admitted to this particular type of carbureter were heated, loss of power would result, attended by pre-ignition and other signs of an imperfect mixture. The unique feature of this carbureter, however, lies in an arrangement whereby a variable quantity of water is supplied to the mixture of kerosene spray and air before it is admitted to the cylinder. The water valve is connected with the crankshaft of the motor so that the supply of moisture to the mixture is increased as the throttle is opened and the spark advanced; when the motor is running idle or is pulling very light loads no water is supplied to the fuel. The purpose of the water is to keep the temperature of the explosion within the limits from which the best results can be obtained, and also to assist in a more perfect combustion of the charge. At the same time that the water absorbs a portion of the excessive heat of combustion oxygen is liberated and the mixture is rendered more completely combustible. One of the troubles sometimes experienced with the use of kerosene in a gasoline motor is the inability of the engine to "pick up" with a load; full load can be maintained when it is once reached, but after throttling the motor, as on a hill, for example, the engine seems unable to respond when power is again desired. This lack of flexibility has been overcome by the introduction of the water spray that automatically accommodates its volume to the power demanded of the motor. It must be remembered, however, that the carbureter in question is designed especially for large, heavy-duty engines, and it should therefore be understood that the omission of the water spray from a kerosene carbureter designed for the average automobile in nowise indicates lack of flexibility in the power plant; in fact, many of the most successful carbureters in use on pleasure cars and trucks have no provision for the introduction of water into the air passage above the atomizing chamber.

HEAT FOR THE VAPORIZATION OF KEROSENE.

While the heat for assisting in the vaporization of the kerosene is usually obtained from the exhaust manifold of the engine, the circulating water can sometimes be used for this purpose by jacketing the carbureter and connecting it with the water system of the engine. As the water in the jackets holds its heat for a greater length of time than does the exhaust manifold, it is evident that the motor could be started directly on kerosene, even after an appreciable interval had elapsed since its previous running, if the stored-up heat in the water jackets were utilized. However, the operation of starting on gasoline, and then switching to kerosene, is neither difficult nor time-consuming and it is the surer method; but in order to obviate the necessity of even this slight trouble, some kerosene carbureters are supplied with an electrical coil placed within the vaporizing chamber. This coil is operated for a few moments by the current obtained from the lighting, starting, or ignition storage battery. But a short time is required to bring the finely divided spray from the atomizing nozzle to the vaporizing temperature, so that the current can soon be turned off, heat for further vaporization being obtained in the usual manner from the exhaust manifold of the engine.

Although the practice of heating the kerosene, either before or after pulverization, is almost universal, theories differ as to the advisability of warming the air with which this kerosene mist is first mixed. In one of the most successful types of carbureters the air is admitted cold after the kerosene has become thoroughly atomized by the mechanical action of the jet and the application of heat to the bowl. It is evident that the admission of the cold air will reduce the temperature of the resulting mixture to the point where condensation will be prevented when the charge comes in contact with the cool metal of the intake manifold. As previously mentioned, the intake manifold should be small enough so that the velocity of the mixture will be high and thus prevent condensation. By the use of cold air in medium-sized engines, however, this difficulty is overcome without the necessity of making any change whatsoever in the intake manifold of the engine. Another method of obtaining the same results, and one which is employed in one of the well-known kerosene carbureters designed especially for marine use, consists in jacketing not only the fuel bowl but the choke tube and throttle as well, so that the mixture is maintained at a high temperature throughout a good part of its journey to the hot cylinder. A carbureter of this type is shown in Fig. 2. The intake for the exhaust is at *H*, the outlet at *O*, the kerosene intake connection at *K*, the gasoline intake connection at *G*, the water intake connection at *W*, and the fuel spray nozzle at *S*.

Kerosene carbureter designers have long since discovered that the amount of heat supplied to the fuel before admission to the cylinder must be regulated to a nicety. It has already been pointed out that with insufficient heat, the kerosene is not properly vaporized. The application of too much heat, on the other hand, will result in what is known as the "cracking" process, in which the kerosene will be split up into its component parts, an ill-smelling exhaust will be ejected, and large quantities of carbon will be deposited on the piston and cylinder heads.

In one of the newest carbureters on the market (see Fig. 3) the mixture is given exactly the right composition in rather a novel way. The heat for assisting the vaporization of the fuel is obtained from the atomized kerosene itself, as soon as the motor is started, and no previous heating is required. The kerosene is atomized when cold in the usual manner; that is, by drawing it, by means of the suction of the motor, through a series of small orifices, which serves to break it up into globules, after which a strong current of air is passed over it for the purpose of further diffusion of the mist. If this mixture is discharged directly onto some cool surface, however, such as the hand, it will be observed that the kerosene will immediately condense and roll off in the form of drops. The atomizer and air inlet are at the top of the carbureter. Immediately below these is a small compartment into which projects the "business end" of a spark plug operated by a coil and set of dry batteries separate from those that may be used for the ignition system of the motor. As soon as the motor is turned over, the spark at the end of this plug is started. As this projects directly into the path of the recently atomized kerosene and air, a portion is ignited. This compartment is of such a size that only about two per cent of the kerosene spray is ignited, but this seems to be sufficient to "burn the excess car-

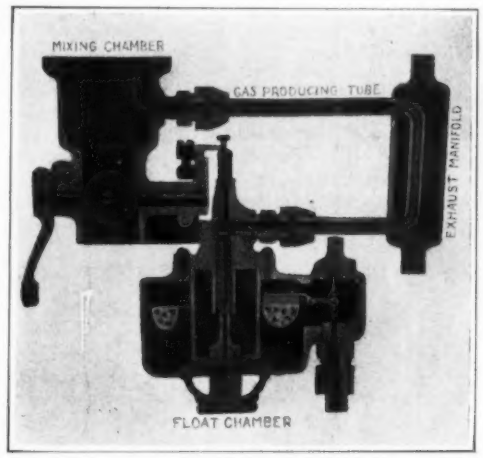

Fig. 5.—Cross-section of carbureter in which exhaust heat is not applied until fuel has been well pulverized. Dotted and Wavy Lines indicate transformation from mist to vapor after application of heat.

bon" out of the mixture and to transform it into an ideal combustible charge for the cylinders. This resulting mixture, if discharged into the air, appears in the form of a white cloud of vapor that does not easily condense, and seems to be as stable a gas as any yet used for internal combustion engines.

While the idea of burning a portion of the mixture directly in the path of the combustible charge may seem like a dangerous system, the flame is effectively prevented from spreading by the use of a wire gauze that holds the fire within the proper bounds in the same manner that the fine wire screen of the miner's lamp admits air to the burner but prevents any of the surrounding inflammable gases from becoming ignited. The location of this wire screen governs the proportion of the mixture that will be ignited by the spark plug, and the proper adjustment is important. A mica window is placed in one side of the spark plug chamber, so that the condition of the flame may be noted. The spark plug is used as long as the motor is in operation, but the inventor of the device is now working on a system which will require the use of the plug only at starting.

KEROSENE CARBURETING DEVICE REQUIRING NO HEAT.

In view of the foregoing methods of carbureting kerosene, it is surprising to learn that a system has been devised in France which entirely does away with the application of heat, either to the raw kerosene or to the atomized mixture. In fact, a motor equipped with this device can be started when cold directly with kerosene as easily as though high-test gasoline were the only fuel used. The attachment can hardly be called a carbureter, in the ordinary sense of the word, inasmuch as it depends for its operation on several electrical and mechanical parts as well as physical properties, and requires a slight change in the design of the engine in order to make its installation satisfactory.

The first point in which this remarkable device

differs from the ordinary carbureter lies in the fact that pure air only is admitted through the inlet valve. The amount of air so admitted is controlled by a slotted, hollow cylinder *A* (see Fig. 4), the orifice in which can be made to register with the opening in the inlet valve through an automatic control connected with the throttle or the gasoline pressure regulator. The raw kerosene is led from the pressure-regulating tank, into which it is forced by a rotary pump, into the atomizer *B* which is screwed into the cylinder head. This atomizer consists of an inverted automatic poppet valve, the head of which projects into the cylinder nearly over the head of the piston. The stem of this valve is hollow, and surrounding it is an auxiliary air space connected with the outer atmosphere. As the liquid kerosene under pressure rushes into the atomizer, it is broken up into fine particles and united with the proper quantity of air admitted through the auxiliary opening and through the hollow stem. To be sure, this is not a *bona-fide* vapor (it is merely a fine spray), but it is admitted directly into the combustion space of the cylinder, mixed with the proper quantity of air entering through the inlet valve and immediately compressed; there has been no opportunity for condensation, for the atomization practically has taken place within the cylinder itself.

The pressure on the fuel is regulated by means of a variable column of mercury *C* extending into the space into which the kerosene is pumped. This presures can be controlled by the same levers that throttle the supply of air admitted to the cylinder, but this would not be sufficient regulation to provide for the demands of the motor at all speeds, if the supply depended entirely upon this pressure and the suction of the piston in the cylinder. To obtain the proper regulation, there has been devised what is probably the most ingenious carburetion attachment to be found in use. Before the raw kerosene is admitted to the atomizing chamber, it is forced through a needle valve at *D*, the stem of which constitutes the armature of a solenoid. This solenoid is a coil of wire that is excited by the current derived from a low-tension magneto. The stem of the needle valve (assuming, of course, that it is made of a magnetic metal) serves as the plunger or armature of the solenoid and is drawn into the interior of the hollow coil whenever the current passes through the wire. When the coil is not excited, the needle valve is held in place on its seat by means of a spring that effectually prevents the passage of fuel to the atomizer when the motor is not running. By means of an electric circuit-breaker which may be geared to the crankshaft of the motor, the number of current excitations or "pulsations" imparted to the coil may vary with the speed of the engine, and a supply of fuel proportionate to the demands of the engine will thus be obtained. This kerosene carbureting device has passed the experimental stage and is now used on many French cars.

To the ordinary motorist, familiar with the comparative simplicity and efficiency of the gasoline carbureter, these various devices for obtaining power from kerosene may seem somewhat complicated, but to the business man who will look deeper and see in them the real solution of the problem created by the constantly increasing cost of gasoline, they give evidence of the stability of the internal combustion engine and of its ability to adapt itself to whatever fuel may be used. These carbureters are in use to-day in all parts of the country, and if the owner of the pleasure car still prefers to pay the excessive price for gasoline, when a satisfactory substitute at half the cost is available, it may be but small consolation for him to know that the arrival of the time is inevitable when he will be forced to make the change. But whether the change will come soon or late, it is a satisfaction to the truck owner to know that one of the most important problems of his delivery and hauling system is being solved, and that the future of motor transportation is brighter than ever, even before gasoline leaped in price.

Ball Bearings—Their Construction and Application*

Advantages of Ball Bearings and Their Use in Industrial Equipment

By F. H. Poor

THE results of extensive tests which have been performed with the view of determining the relative coefficients of friction for various types of ball, roller and sliding bearings, show a marked superiority of the ball bearing as regards the coefficient

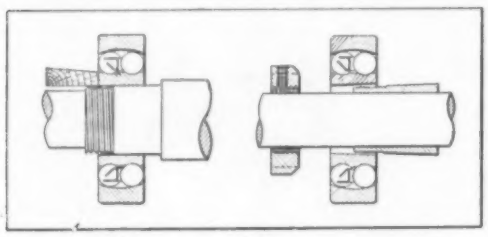

Fig. 1.—Methods of securing the inner race to the shaft.

of friction. These tests also show that the coefficient of friction for ball bearings varies between very close limits at different loads and speeds, while the coefficient of friction for sliding bearings extends through a very wide range for even small changes in speed or load. The friction in sliding bearings is dependent upon the bearing surfaces, the lubricant, the method of lubrication, the load to be carried, and the pressure per unit of measurement, together with the speed and temperature.

It would seem that a roller bearing would be more efficient than a ball bearing, on account of the larger contact surfaces between the outer and inner races, but this is not the case, inasmuch as it is almost impossible to obtain pure rolling motion in a roller bearing. The reasons for this are as follows: (1) It is extremely difficult to commercially produce hardened rollers which are exactly cylindrical. (2) Straight rollers will not carry an end thrust. (3) If there is any tendency for the shaft to twist, or if there is any deflection in the shaft due to the load, there is a tendency for the rollers to twist out of their normal path, and this leaves only a short part of the roller under actual load. To help the roller bearing out, however, there are combinations of annular and thrust roller bearings, but they have not found as wide application as ball bearings have.

Ball bearings are used principally for the following reasons: (1) There is less loss of power on account of the lower coefficient of friction. (2) The friction of a ball bearing is independent of the viscosity of the lubricant, or of the temperature thereof. (3) The frictional resistance at starting is very much lower than in sliding bearings. (4) The scraping of bearing linings and fitting them to the shaft is not necessary. (5) There is practically no danger of the bearings running hot. (6) The bearing housings mounting ball bearings are very much shorter than sliding bearings. (7) A ball bearing of proper construction can adjust itself to deformations of the shaft, or strains in the housings.

The reason why a larger ball can take less load than a smaller ball can readily be understood. It is because with an increased volume it is harder to obtain a thoroughly hardened ball. In the matter of speed, the reduction of capacity of the larger ball is due to the tiring out or "fatigue" of the material. Other tests have shown, however, that the tiring out of the steel is caused by the number of load applications and not by the rapidity with which they change. From actual tests with balls, Prof. Goodman of the Institute of Civil Engineers in England derived a formula for the allowable load, in which he took into consideration the velocity of the balls. These tests have shown that the carrying capacity of a one half inch ball, for example, while it is much greater than that of a one quarter inch ball under static load decreases very much more rapidly than a smaller ball under a given increase in speed for each size.

It is of great importance for all the balls in a bearing to be finished absolutely spherical, and as nearly of the same size as possible. A large ball in a bearing will take more than its share of the load and thus become overloaded; and at the same time, it will have a different velocity from the smaller balls, which will result in sliding friction either between the ball and the retainer, or if there is no retainer, between the balls themselves. First-class balls can now be manufactured within spherical limits of 0.022 millimeter (0.00008 inch) and are sorted in classes in which the diameter of the balls does not vary more than this amount.

A ball bearing of the right design must comply with the following requirements: The balls must have pure rolling motion, and the races must be so designed that without increasing the friction under load, they give a maximum bearing surface.

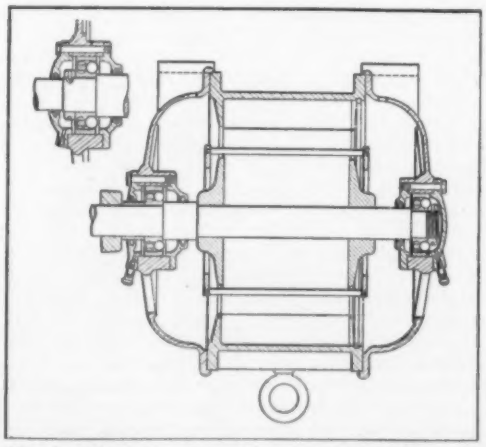

Fig. 2.—Electric motor equipped with ball bearings.

To fulfill the first requirement, the tangents to the balls at their points of contact with the races must be parallel to the axis of rotation of the balls. This rule, however, is frequently neglected. Efforts have been made to solve this problem by designing ball races with three or four contact points for the balls, but the increased number of points of contact for the balls developed considerable additional friction, and practically all bearings actually in general use have only two points of contact.

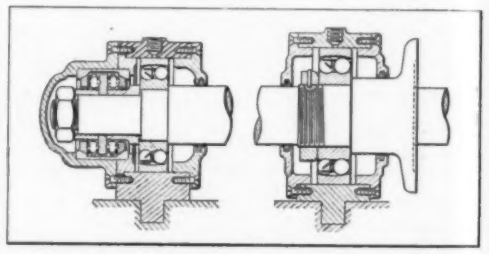

Fig. 3.—Ball bearing applications for combined radial and thrust load.

In the construction which is dealt with in this article, the contact surfaces on both the inner and outer races are practically equal, and in addition to this the bearings have the following distinct advantages: Increased reliability because of the fact that the bearings, though made to standard dimensions, have a double row of balls, and because the method of having the outside race spherically ground allows the bearing to automatically adjust itself to any deflection of the shaft or inaccuracy in the mounting or machine frame structure. Furthermore, both rows of balls are loaded evenly, and it is possible to assemble and disassemble the bearing, if necessary, without destroying it. This last feature may seem extremely simple, yet it is important for the reason that it does away with the slots in the inside and outside rings, and the races are thereby made continuous.

We now come to the discussion of the material from which the bearings are made, which must have the greatest possible hardness in conjunction with toughness after hardening. Furthermore, the steel must be free from slag, and be perfectly homogeneous. Some ball bearing factories are using casehardened races, but aside from the danger of the hardening not being even, there is also the danger in this construction of the races being permanently deformed. It is absolutely impossible to caseharden steel balls because the main requirement to prevent a ball from permanent deformation is through and through hardening. Accordingly, we have to use a material for both balls and races which, in addition to the above-mentioned qualities, has also the quality of being easily and uniformly hardened throughout. The steel must be forged

*Abstract of a paper read before the American Society of Swedish Engineers, and published in *Machinery*.

or rolled so that the grain is as close as possible.

It may be said that the use of ball bearings in rotating machines is practically unlimited. The following points must be observed in their design if ball bearings are to work at their full advantage: (1) We must consider, as we do in other types of machines, whether the load or speed is variable, and the conditions which are to determine the selection of a heavy enough bearing to meet the machine requirements. (2) The bearings must be mounted so that the outside race cannot squeeze out of true. (3) When the shaft is revolving, the inside race of the bearing should be fastened securely to the shaft, making it practically an integral part thereof. The best means of doing this is to drive the bearing upon the shaft and hold it securely between a shoulder on the shaft and a lock-nut, or by using an adapter sleeve made with a taper to fit in the bearing. By using bushings over a shaft between the bearing inner races, several bearings can be held on the shaft by one nut. In no case should there be any play between the inside race and the shaft because of the possible danger that the ball bearing race will peen down the shaft and ruin it. (4) Only one bearing should be held sideways to take up lateral movement of the shaft, the other bearings being mounted free to move laterally in their housings. This is to allow for elongation or contraction of the shaft, due to changes in temperature or other causes. (5) Ball bearings must be lubricated, although the amount of lubrication required is very small. The lubricant must be chemically neutral, and for general applications, a mixture of vaseline and vaseline oil, or a good mineral oil is recommended. (6) The bearings must, in all cases, be protected from dirt, dust, dampness, and oxygen.

Ball bearings have been applied on electric motors with excellent results, a typical mounting being shown in Fig. 2. For this class of machinery the medium type bearings should be selected, and it is important for all of the bearings to be secured to the shaft on account of the high speed and vibration of the machine. It will be noted that the bearing on the left-hand side has a very small lateral clearance in order that it may take up any possible lateral movement of the shaft. The bearing nearest the pulley is left free to adjust itself, and attention is drawn to the two types of mounting for the bearing next to the pulley. The bearing in one case is held securely against the shoulder by a sleeve between the pulley and the inner bearing race, and in the other case by a locking-nut.

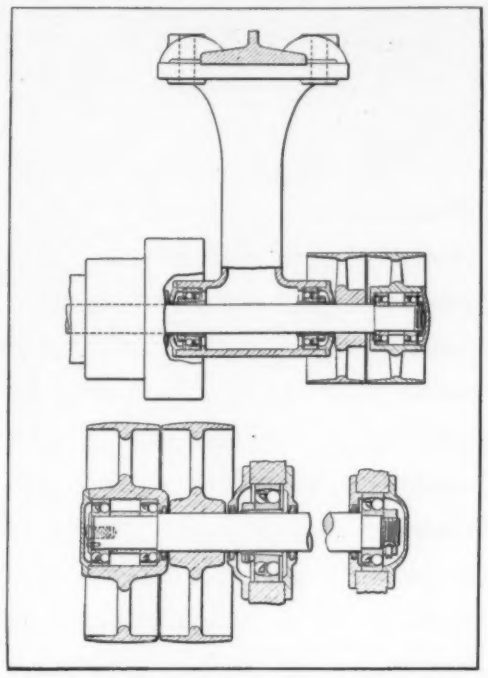

Fig. 4.—Radial bearings on loose pulley countershaft.

Fig. 3 shows a ball bearing mounting for a circular saw spindle. It will be seen that this application of ball bearings is designed for a combined radial and thrust load. In considering ball bearings of various types of machines, it was not definitely stated that the load conditions are of material importance in determining the proper selection of bearings for different duties. As a general practice in bearings selected for belt-driven machines, it is customary to allow a factor of safety of approximately five, that is, the ball bearings must be selected of such a capacity that the catalogue ratings are practically five times the normal figured load to which the bearings are to be subjected. This factor of safety may seem extremely large, but all of us appreciate that in many cases the tension of the belt is subject to the careless handling of inexperienced workmen, and one cannot foresee to what extent the belts themselves, or the bearings, may be subjected to abuse. In addition, it may be pointed out that belts running at high speeds are usually heavy, and in addition to the pressure to which they subject the bearings, there is every likelihood that pulleys will suffer the constant pound and shock of heavy belt lacing, joints, or the possible accumulation of lumps of grit, sticks of wood, or other materials which may be caught between the belt and the pulley. This is particularly true in train lighting service, woodworking machines, etc.

In the matter of selecting bearings for woodworking machines, we have found that it is necessary to allow a wide factor of safety, particularly on band saws. These saws, in operation, are usually adjusted to a certain tension by means of levers or balancing weights. If the saw becomes heated there is bound to be expansion in the blade, and while the adjusting levers or balance weights may compensate for the increased length of saw, due to heating, the bearings are liable to be cramped after the machine is shut down, due to the contraction of the saw blades. On gear drives it is customary to allow a factor of safety very close to three times the normal driving power of the gears, this factor being used for the purpose of allowing for backlash, sudden shocks, or reversals.

Hydraulic Plate Shears

By the Paris Correspondent of the Scientific American

THE steam hydraulic slab shears shown on our front page are of interest not only on account of their powerful build, but also for the various electric and hydraulic features embodied in their makeup. The shears were built by a firm of Sheffield, England, for use in a Scotch construction works. The new shears are built for handling and cutting hot steel plate of 24 inches thickness by 48 inches width, or 18 inches by 66 inches width, and it takes only 12 seconds to make the cut and come back to position. In the middle of the upper framing is mounted the main hydraulic ram for driving down the shear blade for cutting the slab, this blade working together with a corresponding fixed blade mounted on the table. The hydraulic ram is of large size and has 41 inches diameter with 2 feet 4 inches stroke. On the present steam hydraulic system the hydraulic pressure is produced by using a pair of steam-hydraulic intensifiers which work with a steam pressure of 80 to 100 lbs. per square inch, making the maximum hydraulic pressure for the shears 2 to 2½ tons per square inch.

In order to guide the ram in an exactly vertical stroke, its lower end is fitted into an ample crosshead which slides upon four steel columns. The shear blade is mounted on the lower end of the crosshead. On the massive foundation are the front and back roller tables for the ingoing and delivery sides, the feeding-in side, being shown in foreward position on our photograph. The feed mechanism comprises a set of 5 cast-steel rollers of 21 inches diameter and 5 feet 3 inches length, the first three rollers being geared together, while the two rollers lying next the shears are mounted on a spring carriage so as to allow for play and to give the necessary adhesion of rollers to slab for driving it forward. These two rollers are driven by friction disks in order to save space. The design of the delivery end of the machine presents points of special interest.

As in all slab shears the delivery end has a yielding table upon which the end of the slab rests while it is being cut. Ordinarily this yielding table is simply depressed by the pressure of the shears. This is not altogether satisfactory, and in the new machine the table is caused to drop by an independent movement which is adjusted so as to keep pace exactly with the descent of the shear. Like the feed end, the delivery table also carries a set of geared rollers. But these are mounted in a square box frame moving in a pit. Underneath the table is quite an elaborate mechanism to give it the required motion. The frame is supported as a whole upon a pair of hydraulic cylinders and descends under hydraulic pressure at the same rate as the shears during the cutting operation.

The rollers are driven by a 40 horse-power electric motor, while a press holding the slab down flat upon the roller is operated from a separate 10 horse-power electric motor.

The Arabian Date Trade

IN OMAN there are groves of date palms covering an area of sixty miles long and averaging two miles in width, in the coast country known as the Bahtinah; an estimated half-million trees in the Wadi Semail; large groves at Rostock—in fact, everywhere where water is to be obtained this plant is cultivated. The uses of the product of the palm are many. The stems furnish timber which, though of a poor sort, is very valuable when no other is to be obtained; buds of the male palm are considered a great delicacy; the habitations of all the poorer natives are made of the fronds; the fiber of the stem is twisted into serviceable ropes; the seeds are pounded and made into cattle food; while the fruit is at once the staple food of man and beast, and an article of export equal in value to all other exports from Oman combined. About 15,000 tons of dates, valued at over $600,000, are shipped annually from the port of Maskat in steamers, and the export in native vessels is perhaps as large, for every year at the beginning of the season the harbors of the gulf are full of dhows and baggalas from the Yemen, the African coast, and Zanzibar, waiting for cargoes of dates.

The annual rainfall in Oman is only about five inches, consequently irrigation is everywhere necessary; and as the methods and appliances are very simple, the lifting of the enormous volume of water needed involves a tremendous amount of labor. In the district of Maskat there is one contrivance which is used for this purpose. It consists of a sheave fixed some 12 or 14 feet above the well, a rope, and a leather bucket made with a flexible rent in the bottom, so as to be self-emptying. Power is supplied by a bullock traveling up and down an inclined plane excavated in the ground, and it is possible for one man and beast with this appliance to raise a thousand gallons over a lift of 20 to 25 feet in an hour, though work is rarely done at such a rapid rate. Many efforts have been made to introduce improved pumping machinery, but so far without success. According to the American consul at Maskat, date trees are propagated solely from offshoots, and never intentionally from seed. The young trees ordinarily come into bearing the fourth year after being set out. Pollination is effected by hand. Small crops, principally alfalfa, are grown in the spaces between the trees. In Oman, dates begin to ripen in May, and from then on until November the fresh fruit (rattab) is always to be obtained in the bazaars. There are numberless varieties, each with a separate name, but not more than half a dozen kinds are readily distinguishable by anyone but an Arab or an expert. The dates grown near salt water are little esteemed, being called "donkey dates" from the fact that they are largely used as food for these animals. Those from the mountain valleys are prized most highly, the variety known as the Hlassa being considered best of all, both by natives and Europeans. A prominent date grower and dealer in Oman gives the value of an average palm at $40, and the annual yield as 400 lbs. of dates. Dry, wet, and hand-selected dates are exported. The first are sent to India, where they are used as food, and where their consumption is prescribed as part of the various social and religious observances. The price is about 2½c per lb. In harvesting dates which are to be shipped as "wet," they are piled upon a piece of matting spread upon the ground, trampled into a compact mass, and then packed in wicker bags holding about 100 lbs. The larger part of the entire crop is prepared in this manner, and from Maskat sent to Mecca, the Yemen, and in enormous quantities to India. Recently India has begun to take small quantities of hand-packed dates of second quality, but the choice hand-selected dates are all shipped to the United States, and the methods adopted in getting them upon the market are entirely different from those prevailing in handling any other kind. These dates are of a variety known as Fard. They are all grown in the Wadi Semail, a mountain valley about seventy miles from Maskat, and every one that is fit to ship goes to America, their pre-eminence in that market being due to their superior keeping and shipping qualities. The trade is an old one, there being records of sailing vessels from Salem and New Bedford leaving Maskat date-laden for New York as far back as 1843, and the business is known to have existed before that time. The Wadi Semail is a perennial stream, and all available land in its vicinity is irrigated by a fine system of ditches, so old that the Arabs have no tradition as to when or by whom the canals were built. The Fard dates—which the natives believe cannot be grown outside this one valley—are harvested in the last days of August, and are bought by dealers or taken by money-lenders who have advanced funds against the crop at a price which usually realizes to the grower a little more than 1 cent a lb.—*Journal of the Society of Arts.*

Modern Methods of Measuring Temperature—I*

Electric and Other Thermometers for Use in Industrial Operations

By Robert S. Whipple

THERE are few manufacturing processes in which the question of temperature is not involved, either in the early or the later stages, and it may therefore be helpful to consider briefly what methods are now available for the measurement of temperature.

Expansion Thermometers.—The earliest thermometers were of the expansion type, and were due to Galileo. They consisted of a glass bulb with a capillary tube attached, the bulb being filled with alcohol which expanded with temperature, the expansion being indicated by the movement of the alcohol up or down the capillary. The scale on the thermometer was purely an arbitrary one, and it was not until Hooke in 1681 suggested the melting-point of ice, and the boiling-point of water, that any attempt was made to obtain a fundamental scale of temperature. Thirty years afterwards, in 1714, Fahrenheit suggested his scale. As the Fahrenheit scale is still the one almost universally used by English and American engineers, it may be of interest to know how Fahrenheit obtained his scale. The explanation

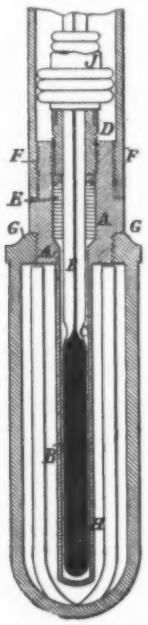

Fig. 2.—Thermometer (Hohman and Maurer).

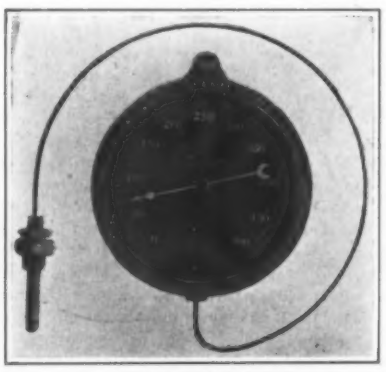

Fig. 4.—Index thermometer.

generally accepted is due to the late Dr. Gamgee.[1] The lower fixed point of the scale was determined by a mixture of snow and salt, and the upper by placing a thermometer under the arm-pit, or inside the mouth of a healthy man. In the earlier thermometers the interval between these two fixed points was divided into twenty-four parts, and later on those parts were divided into fourths, making ninety-six parts. It was subsequently found that, by a pure coincidence, the 32 deg. corresponded to the melting point of ice, and the 212 deg. to the boiling-point of water.

The Centigrade scale was introduced by Celsius, and is the one now almost universally used on the Continent and in Great Britain and America for scientific work. On this scale the freezing-point of water is marked 0 deg. and is called zero, and the boiling-point is marked 100 deg., the interval (frequently referred to as "the fundamental interval") being divided into 100 equal parts. Mercury was adopted at the outset as the thermometric substance, presumably because it was easier to distinguish

Fig. 1.—Types of mercury thermometers.

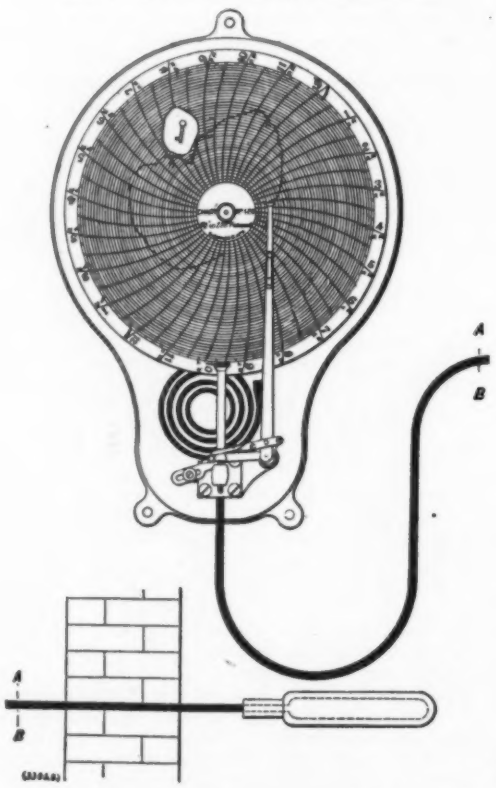

Fig. 5.—Diagram showing principle of thermograph and index thermometer. (Hohman and Maurer.)

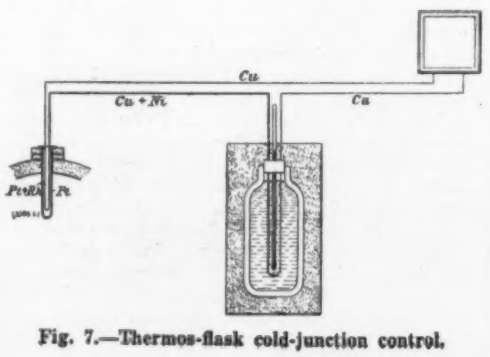

Fig. 7.—Thermos-flask cold-junction control.

than alcohol in the fine capillary tubing, and for nearly all work about atmospheric temperature it has maintained its position. This is not surprising when one considers over what a large range of temperature (—39 deg. to 357 deg. Cent.) it is liquid; its regularity of expansion (as compared with the gas thermometer); the ease with which it can be obtained pure; its property of not wetting glass; its low vapor pressure; and its low specific heat and high conductivity which enable it to take up readily the temperature of its surroundings.[2]

As soon as any attempt was made at accurate thermometry, it was realized that serious errors were introduced owing to the change in volume of the glass bulb of the thermometer with heating. Glass when heated and allowed to cool does not immediately return to its original volume, and for many years all standard thermometers were made from thermometer tubes, which, after prolonged heating, had been stored for thirty or forty years.

Dr. C. Guillaume,[3] in a long investigation into the qualities of various glasses for use as thermometer tubes, found that the more infusible glasses were more stable, and adopted the French *verre dur* for his standard tubes.

Fig. 3.—Separate socket fitting, section.

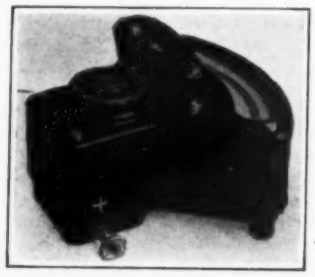

Fig. 6.—Temperature indicator, portable.

At the Reichsanstalt, Berlin, the Jena glasses 16^{III} and 59^{III} have been found to be most generally satisfactory, and these glasses have been adopted by the majority of makers of high range mercury thermometers throughout the world. The price of such thermometers is very slightly higher than those made with the ordinary English glass, and it is wise to insist upon them, as the zeros will be found to be much more constant than those in thermometers made with English glass.

The methods of correcting for the errors found in the mercury thermometers have been fully investigated by Guillaume, Chree,[4] and other workers. The close attention given by manufacturers to the many points which have to be investigated has led to the production of very accurate thermometers. It may, however, come as a surprise to engineers to know, that assuming a high-grade mercury thermometer has been studied at one of the National Physical Laboratories and its corrections

* Paper read before the Institute of Mechanical Engineers.

[1] A. Gamgee, Proc. Camb. Phil. Soc. 1890, vol. viii, part iii, page 95.

[2] See "Theory of Heat," T. Preston, 2nd Edition, page 119.

[3] C. E. Guillaume, *Traité Pratique de la Thermométrie de Précision.* Gauthier Villars, Paris.

[4] C. Chree, Phil. Mag., March and April, 1898.

determined, it is possible to measure temperatures with it throughout its range to an accuracy of 0.001 deg. Cent. This accuracy is largely possible because the two fundamental points (0 deg. and 100 deg. Cent.) are placed on every such thermometer, whatever may be its range. This is accomplished by the insertion of small chambers in the capillary. Fig. 1 shows how thermometers may be made of practically any range, openness of scale and of reasonable length, and yet have the two fundamental

Fig. 8.—Temperature indicator. Wall type.

points marked upon them.

For nearly all engineering work an accuracy of 0.001 deg. Cent. is not required,[5] and the recent developments in mercury thermometers have been in the direction of making them easier to read and more robust.

The lens-front thermometer tube was invented by Luigi Peroni,[6] and the world undoubtedly owes him a great debt, as by its means a very small capillary may be used, and yet the mercury column can be read without difficulty. Another important invention, but the name of the inventor is unknown, is the introduction of an inert gas, such as nitrogen, or carbon dioxide, under pressure above the mercury in the tube of the thermometer. The introduction of pressure into the tube raises the temperature at which the mercury boils, thus permitting a thermometer to be used up to a temperature of 540 deg. Cent., this limit of temperature being due to the softening of the glass envelope. The pressure above the mercury surface also prevents the breaking up of the mercury column during transit. Although mercury thermometers have been used industrially for many years, yet no serious effort, as far as the author is aware, was made to fit them for the rough-and-tumble requirements of engineers until the Hohman and Maurer Manufacturing Company introduced into the United States their thermometers with special mountings and tube-protecting devices. These are worthy of a short description. The tubes of the thermometers are made of Jena glass, which, after the mercury has been introduced, are filled with CO_2 under pressure. The thermometers are then annealed for three days at a temperature of 540 deg. Cent. A great deal of thought has been given to the supporting of the thermometer tube. The tube, except that portion forming the scale, has asbestos cord wound on it throughout its length, Fig. 2, and is then placed inside a steel tube J, which is fixed to the steel piece *D*. The bulb *B* of the thermometer is inserted into the thin steel socket *H*, the space between the bulb and the interior of the socket being filled with mercury. *D* is screwed down on to the asbestos yarn *E*, which forms not only a stuffing-box to prevent the escape of the mercury, but also gives an excellent support to the bulb. The exterior of the tube *J* is covered with asbestos yarn filling the space inside the outer metal tube *F*. A wire-guard *G* forms an additional protection to the bulb. The thermometer tube is lens-fronted, and the scale part is protected by a metal case. One of the useful features shown in the design of these thermometers, when used for the measurement of steam temperatures, is a separate socket, Fig. 3. This socket is screwed into the steam-pipe, and the stem and bulb of the thermometer, which is accurately ground to fit the interior of the socket, is screwed into it. The contact between the walls of the socket and the bulb being so intimate, there is practically no lag introduced and there are none of the drawbacks of mercury cups.

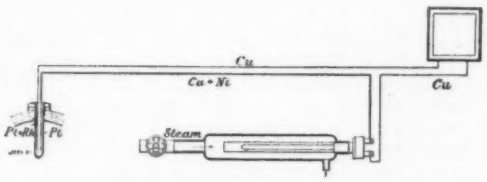

Fig. 9.—Steam hypsometer cold-junction control.

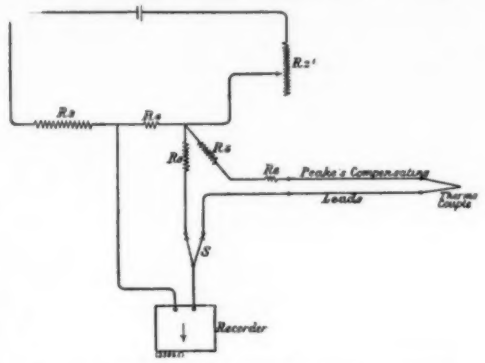

Fig. 11.—Scale control board (simple pattern). for use with thermo-electric pyrometers.

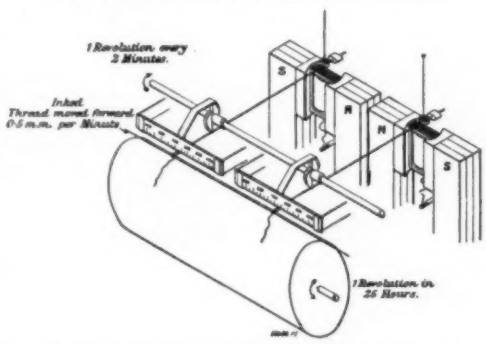

Fig. 12.—Diagram of double thread recorder. (Darwin.)

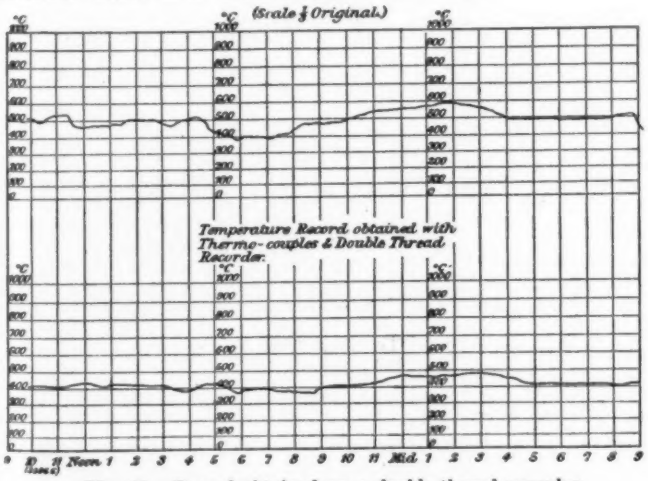

Fig. 13.—Record obtained on a double-thread recorder.

Fig. 10.—Potentiometer. (Rosenhain and Melsom.)

Some of the German manufacturers[7] have developed excellent thermometers in which the envelope is made of quartz, the mercury being under pressure. These thermometers may be employed up to temperatures of 700 deg. Cent. Tin has been substituted for mercury by Dufour, and such thermometers have been used up to 1,000 deg. Cent., but they have not come into general use. It is of course impossible to have the two fundamental points upon such thermometers. For very low temperatures, such as the measurement of the temperature of liquid air and even lower temperatures, gasoline in glass or quartz may be used.

For many years various methods have been tried for recording at a distance the readings of mercury thermometers, but they all, practically without exception, have broken down owing either to unsatisfactory electrical contacts or complications in the recording or indicating mechanisms. Mr. Arthur Barry[8] has, however, introduced a system which, the author understands, works satisfactorily. It consists of a mercury-in-glass thermometer, in which a high resistance wire is stretched from the bottom of the bulb along the capillary. The apparent resistance of the wire is increased or diminished as the mercury falls or rises in the thermometer tube. By means of simple electrical arrangements, the resistance of the wire can be measured from a distance, and the temperature deduced from the galvanometer readings; if a direct deflection galvanometer is employed the readings may be given directly in degrees of temperature. The wire employed is one of the bronze alloys, and has been found to remain constant in resistance and unaffected by mercury over considerable periods of time.

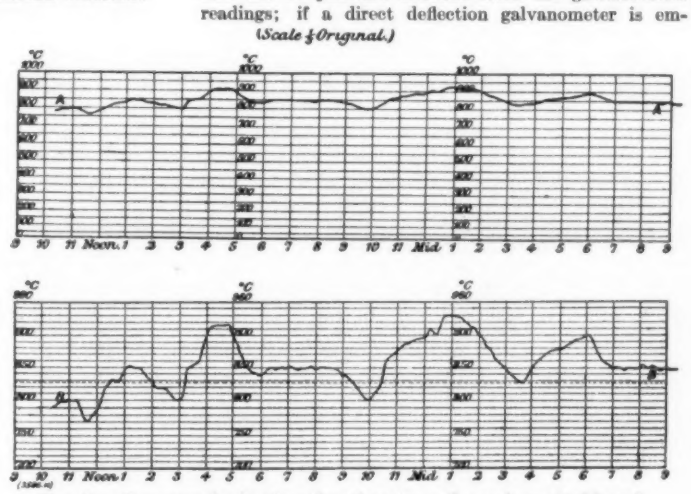

Fig. 14.—Two records showing the advantage of a scale control board.

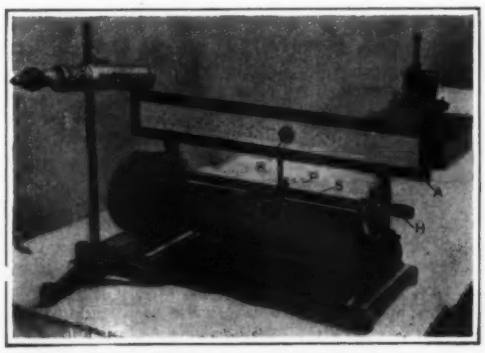

Fig. 15.—Curve Tracer (Brearley).

Mercury thermometers can now be satisfactorily arranged to sound an alarm when a given temperature has been obtained. A platinum wire is fused into the capillary tube of the thermometer at a point corresponding to the temperature at which it is desired to sound the alarm, a second wire being fused into the bulb of the thermometer. These wires are connected to a circuit containing a post-office relay, which controls a switch capable of making and breaking a current large enough to ring a large alarm-bell. The current broken in the

[5] As an instance where engineers have been keenly interested in temperature measurement to this degree of accuracy, mention must be made of the work of Prof. Barnes, on frazil ice. He has shown that temperature differences in the water temperature of 0.001 deg. Cent. may bring about the formation of frazil ice, which may throw out of action a complete hydro-electric plant. In his case all the measurements were made with resistance thermometers. See "Ice Formation," Chapter V. H. T. Barnes. Chapman & Hall, Ltd., London.

[6] See British Patent Specification, No. 317, 1878.

[7] Particularly Messrs. Siebert and Kühn, Cassel.

[8] See British Patent Specification No. 23,461, 1906.

thermometer circuit itself does not exceed eight milliamperes, so that the mercury surface in the thermometer keeps clean almost indefinitely. If wires are inserted in the thermometer stem at other points, and a selector switch employed, then the alarm will be sounded at whichever of these temperatures is selected. It is usual to arrange that the alarm will ring on ascending temperatures; it is not difficult, however, to make it sound on falling temperatures.

Even although the improvement in the mounting of mercury-in-glass thermometers has done so much to render them robust and suitable for engineering work, yet there is always the drawback of the comparative difficulty in reading the thermometers and the risk of breakage.

Several thermometers of various kinds have been developed in which metal tubes have been substituted for the glass envelope, and gases, saturated vapors, or liquids for the mercury. The most successful of the gas and saturated vapor types has been that developed by M. Fournier. Although thermometers of a similar type had been known for some years, yet he was the first to develop it commercially on a large scale. In America the mercury-in-steel tube thermometer has been largely used owing to the efforts of the Bristol and Taylor Instrument Companies. The models due to this latter Company have now been placed on sale in England by the Cambridge Scientific Instrument Company, and are accurate, simple in action and robust. They consist of a steel bulb, Fig. 5, to which a steel capillary tube is attached, the latter being connected to a form of Bourdon pressure-gage. The bulb and its capillary are filled with mercury under pressure and the system is hermetically sealed. The hand attached through some simple mechanism to the pressure-gage is arranged to point over a dial or to carry a pen which writes on a circular sheet of paper rotated by clockwork. The bulb of the thermometer can be made of various dimensions with different mountings suitable for the different purposes and ranges for which they are required. Fig. 4 shows an index thermometer with a bulb and screw socket especially adapted for recording the temperature of steam in a steam-pipe. The recording or indicating mechanism may be placed at distances up to 75 feet from the bulb of the thermometer; owing to the smallness of the effective diameter of the capillary tube and therefore the small volume of mercury contained in it, as compared with the bulb, changes in its temperature have no appreciable effect on the readings obtained. The instruments may be relied upon up to temperatures of 540 deg. Cent. (1,000 deg. Fahr.).

Thermometers depending on the unequal expansion of two materials such as steel or carbon were employed for many years, but owing to their instability of zero and the dependence of their readings on the depth to which they were immersed. they have become so discredited that they can no longer be considered useful thermometers.

Thermo-Electric Thermometers.—It is evident that, useful as they are, expansion thermometers have a limited range of temperature over which they may be employed, and some of the other physical properties of materials must be used, as a means for the determination of high temperatures. In 1822 Seebeck made the discovery that when a junction of two dissimilar metals is heated, a thermo-electric force is set up at the junction which gives rise to a current of electricity when the heated junction forms part of a closed circuit, the magnitude of the current and its direction depending on the metals employed. Beequerel, who first proposed to use this method for determining temperatures, employed a platinum-palladium couple, and his son Edm. Beequerel, who further developed the method, pointed out the importance of using a galvanometer of high resistance.[9] The platinum-palladium couple proved to be unreliable, and it was not until both Barus and Tait proposed the platinum, platinum-iridium (10 per cent Ir.) couple, that a satisfactory couple was produced. Shortly afterwards Le Chatelier showed that platinum-rhodium (10 per cent Rh.) was a more stable alloy at temperatures above 1,000 deg. Cent., and adopted the platinum, platinum-rhodium (10 per cent Rh.) as the standard thermo-couple material. His work has since been confirmed by a large number of workers, and more recently by Dr. Day and his colleagues of the Geophysical Laboratory at Washington.[10]

Of recent years, owing to the very high price of platinum, many attempts have been made to find satisfactory thermo-couples made of comparatively inexpensive wires. The most satisfactory of these so-called "base" metal couples is silver-constantan (the latter being an alloy wire sold commercially as a resistance material, and consisting of copper 60 per cent, nickel 40 per cent), which may be used up to a temperature of 700 deg. Cent. (1,300 deg. Fahr.). Copper is frequently used instead of silver as one element of this couple, but in practice it will be found to be not nearly so trustworthy as the silver, at any rate for temperatures above 500 deg. Cent. For temperatures from 700 deg. Cent. to 1,100 Cent. (2,000 deg. Fahr.), the Hoskin's couple, which consists of a nickel wire used in conjunction with a nickel-chromium (10 per cent Cr.) one, may be employed.

One of the great drawbacks in all thermo-couple work has been the difficulty of reproducing wires giving the same electro-motive force at the same temperature from different ingots of alloy. Messrs. Heraeus, of Hannau, and Messrs. Johnson, Matthey and Co., of London, have both succeeded in overcoming the very considerable difficultles in the manufacture of platinum-iridium and platinum-rhodium ingots; and thanks to their work, the pyrometer manufacturer can now supply thermo-couples giving the same electro-motive forces at the same temperature as those he may have supplied a few years previously. The same statement cannot be made about the base-metal couples, but as in many cases the pyrometer maker holds a large stock of the wire he can generally repeat a given E.M.F. at a given temperature to within 5 per cent.

The electro-motive forces given by various thermo-couples differ very much, as the following table of the electro-motive forces given by some of those in very general use at a temperature of 500 deg. Cent., will show. In each case the cold junction temperature is 0 deg. Cent.

Name of Thermo-couple.	Approximate electro-motive force in millivolts at 500° C.
Platinum-platinum 10 per cent. rhodium	4·4
Platinum-platinum 10 per cent. iridium	7·4
Nickel-nickel 10 per cent. chromium (The Hoskin's couple.)	10·0
Iron-nickel	12·0
Iron-constantan	26·7
Silver-constantan	27·6
Copper-constantan	27·8

The relation between temperature and the E.M.F. produced by a thermo-couple when the cold junction is maintained at 0 deg. Cent. is usually given in the form of an equation of the form

$$\log e = A \log t + B,$$

where e = E.M.F. of the thermo-couple in millivolts,

t = the temperature of the thermo-couple in degrees Centigrade,

and A and B are constants depending on the wire employed.

For the chief thermo-couples in general use at the present time this equation is as follows:—

Platinum-platinum rhodium

approximately $\log e = 1.19 \log t + 0.52$.

Platinum-platinum iridium

approximately $\log e = 1.10 \log t + 0.89$.

Silver-constantan " $= 1.14 \log t + 1.34$.

The constant of the wires of which the majority of thermo-couples are now constructed are determined by the various National Physical Laboratories, and the pyrometer manufacturer is always prepared to supply a table giving the constants of the wire of the thermo-couple he is supplying.

It will have been observed that, in the statement made above as to the electro-motive force given by a thermo-couple at a given temperature, the reservation was made that the cold junction is at 0 deg. Cent. A very little reflection will show the importance of this stipulation, because, as the electro-motive force depends on the difference in temperature between the hot and cold ends of the electric circuit, it is obvious that the temperature at one end must be known before the other can be determined. The control of the temperature of the cold junction, as it is generally called, has been the bugbear of all thermo-electric pyrometry. In accurate thermo-electric work, the universal practice is to immerse the cold junction in melting ice and to adopt the potentiometric method of measuring the electro-motive force given. In industrial practice this cannot be done, as it is almost impossible to maintain a vessel full of ice close to a furnace. For the moment it may be assumed that the galvanometer, generally referred to as the recorder or indicator, to which the thermo-couple is connected, is placed in a spot which is not abnormally heated, nor subject to great variation in temperature. It is only necessary therefore to run the wires from the hot end of the thermo-couple straight to the galvanometer, and this is the course generally adopted in the case of the base metal couples. Owing to the costliness of the material, it is impossible to adopt this course with the platinum couples, and several proposals have been made to overcome the difficulty. Messrs. Hartmann and Braun water-cool the head of the pyrometer. and Mr. Paul provides a supplementary couple with one end water-cooled, by means of which the temperature-difference between the hot and cold ends can be determined. The most satisfactory method is one originally due to Bristol,[11] but suggested independently by Peake,[12] in which an inexpensive alloy is substituted for the costly platinum wires, the alloy being so chosen as to give the same E.M.F. against copper as that given by the platinum, platinum-alloy couple. The resultant E. M. F. generated by this compound couple is the same as if the entire couple were of platinum, platinum-alloy. Experiments show that the compensation given by these alloy wires is correct to within 10 per cent up to temperature of 300 deg. Cent. (570 deg. Fahr.).

For accurate work it cannot be assumed that variations in the temperature of the vicinity of the galvanometer are of no importance. Corrections must be applied to reduce the readings to the correct values at 0 deg. Cent. In many instruments the scale over the range 0 to 100 deg. Cent. is closely divided, and a large zero adjustment is provided to enable the zero reading to be set (on open circuit) at the temperature of the instrument itself. In this manner the cold junction temperature is corrected for and the instrument gives a true reading. In use, however, with the temperature continually changing, the setting of the zero is tedious and is apt to be neglected and some method must be adopted in which the cold-junction temperature is controlled independently. The simplest way of doing this is to use a Thermos-flask filled with oil, into which the cold junction of the thermo-couple, or of the compensating leads is placed, the point at which the copper leads join the couple being placed near the bottom of the flask. If the flask is surrounded with lagging, as shown in Fig. 7, it will be found that the temperature inside will not vary by more than two or three degrees, although the temperature of the surrounding air may range through 20 deg. or 30 deg. Cent. A simple and effective control is shown in Fig. 9, in which the cold junction is placed in a tube from which steam is allowed to escape to the atmosphere. The quantity of steam required is very small, and even allowing for extreme barometer ranges the temperature of the junction cannot vary more than 1.5 deg. Cent. With an instrument having a high resistance 100 (ohms), and a low temperature coefficient (0.05 per 1 deg. Cent.), the effect of a variation in temperature of 20 deg. Cent. (a large change in atmospheric temperature) is only 1 deg. Cent. on the reading and is practically negligible. The galvanometer itself is affected by the changing temperature, and it may be necessary sometimes to correct its readings. Some galvanometers, however, have a much higher temperature coefficient, and various ingenious devices have been made to correct automatically the readings of the galvanometer for variations in its temperature, amongst them may be mentioned those due to Darling, Siemens and Halske, and Thwing.

Two methods of measuring the thermo-electric force generated by a couple are employed. The first, already referred to above, is that usually adopted industrially, namely, the direct measurement of the millivolts generated on a direct deflection galvanometer or milli-voltmeter. This instrument is generally of the moving coil type, in order that it may be unaffected by moving masses of iron or stray magnetic fields. As explained previously, it is advisable that it should have a high resistance. The moving-coil galvanometers supplied by all the pyrometer manufacturers are the same except for modifications in details. The instrument shown in Fig. 6 may be taken as a typical one. The range of temperature over which it can be made to operate depends on the thermo-couple employed, the resistance of the galvanometer coil and the resistance placed in series with the coil. The ranges almost universally adopted for such instruments when used with the following couples are approximately:—

Platinum, platinum-rhodium,	0–1,400 deg. Cent.[13]
Platinum, platinum-iridium,	0–1,000 deg. Cent.
Nickel, nickel-chromium,	0–1,000 deg. Cent.
Silver-constantan	0– 800 deg. Cent.
Copper-constantan,	0– 500 deg. Cent.

For use in situations when it is advisable to have the instrument permanently installed, the model shown in Fig. 8 will be found most generally useful.

The second or potentiometric method of measuring the electro-motive force of the couple is undoubtedly the more accurate of the two, owing to it being a null, or balancing method, and thus eliminating any errors due to the resistance of the leads and couple. For this reason it has been almost universally adopted for precision work with thermo-couples. The method is extremely simple; the electro-motive force from the thermo-couple is balanced against that given by an accumulator, the

[9] See "The Measurement of High Temperatures," page 101, by G. K. Burgess and H. Le Chatelier. Chapman & Hall, Ltd., London.

[10] "The Constancy of Thermo-elements." W. P. White, *Physical Review*, vol. xxiii, December, 1906.

[11] British Patent Specification No. 14,544 A. D. 1904.

[12] British Patent Specification No. 370 A. D. 1909.

[13] Some German manufacturers divide their galvanometer scales to 0-1,600 deg. Cent. As it is impossible to find a protecting tube that will live above 1,400 deg. Cent. the upper part of the galvanometer scale is wasted, and might be better employed by allowing the whole temperature scale to be opened out.

electro-motive force of which has also been similarly balanced against that given by a standard cell.

A simple form of the potentiometric method, when applied to the direct-reading moving-coil galvanometer, has very much increased its usefulness, by opening out the scale to double its normal length. A potential drop is given by means of the battery across the resistance R_0, Fig. 11, and against this is opposed the electro-motive force of the thermo-couple. By modifying the resistance R_1 and R_3 one can vary the range of temperature over which the electro-motive force of the couple balances that of the accumulator, and hence alter the temperature scale of the galvanometer. In order to correct for variations in the accumulator voltage, a test switch S and test coil R_2 are provided, and these are so adjusted that when the switch is on the test stud, the galvanometer pointer should be deflected from one extreme to the other. When this is not the case, the variable resistance R_2 is adjusted until it is so. By means of this arrangement—generally referred to as the "Scale Control Board"[14]—the ordinary commercial galvanometer or indicator can be provided with two scales of twice the openness of the normal scale. The two scales are generally from 0–500 deg. Cent. and 450 deg. to 950 deg. Cent., but can obviously be varied by altering the resistances in the system.

Dr. W. Rosenhain and Mr. Melsom have developed a somewhat similar arrangement as a Works Potentiometer, but have added some refinements so that it may be used as a portable standard of reference. The instrument, Fig. 10, is provided with a standard cell C, against which the accumulator A can be adjusted by means of the rheostat R. The resistance S and P are so arranged that temperatures over a large range can be measured. The instrument may be used to measure from 0-40 millivolts to an accuracy of 0.1 millivolt. This will cover the whole range of temperature met with in industrial thermo-couple work.

For accurate research work more sensitive galvanometers must be employed, and greater precautions taken to avoid thermo-electric effects at the switch contacts. A slide wire, or a series of very small resistances, must also form a part of the instrument. Several potentiometers suitable for such work have been described.[15]

For the autographic recording of temperature, the photographic arrangement originally due to Le Chatelier and then to Sir W. Roberts-Austen is still the only way of recording very small and rapid changes in temperature. The drawback of being unable to see the record until it is developed and the trouble of developing, have led to the almost complete abandonment of this method of registration, except for purposes of accurate research. In the majority of recorders now in general use, the galvanometer pointer or boom is depressed intermittently by clockwork, or some simple electrical mechanism, on to either an inked thread or typewriter ribbon which is pressed on to a chart mounted on a rotating drum (clock driven) the resulting record being a series of ink marks. In some instruments the boom is intermittently depressed on to a smoked chart attached to a disk which is rotated by clockwork and a particle of soot is removed at each depression. Thus in either case a record of the galvanometer movements is left on the chart. The thread recorder, invented by Mr. Horace Darwin, may be taken as a typical example of one of these recorders. The instrument is shown diagrammatically in Fig. 12. An inked thread is stretched above the paper and the chopper bar or guillotine is allowed to force the end of the galvanometer pointer down on to the thread which, in its turn, is depressed on to the paper, making an ink dot. The movement of the chopper-bar is controlled by means of a cam which is operated by clockwork, the chopping action taking place either every minute or half minute as desired. The record thus produced consists of a series of ink dots which merge into a continuous line. The action of the clockwork is so rapid that the galvanometer pointer is only under control by the chopper-bar for less than two seconds out of the minute. The figures both illustrate a double recorder in which two galvanometers connected to two separate thermo-couples are recording on the same drum. The galvanometers are initially adjusted to give a complete deflection to 80 millimeters across the paper for an electro-motive force of 1 millivolt applied to the galvanometer terminals. They are then finally adjusted for use with any particular thermo-couple or for any specified range by means of small subsidiary resistances. Fig. 13 is a reproduction of a record obtained with two thermo-couples.

The scale control board can also be used with the recorder, and this forms one of its most important applications, for as the sensibility of the galvanometer is high, the scale can be magnified considerably, say four or five times. Thus a complete deflection of the galvanometer (80 millimeters on the paper) when used with a platinum-rhodium couple can be made to equal 300 deg. Cent., and at a particularly useful part of the temperature scale, say, 600 deg. to 900 deg. Cent. This at once allows of a considerable increase in the precision of temperature control. Fig. 14 is a reproduction of a record obtained from two galvanometers connected to one thermo-couple; it will be observed how much more open is the scale of the instrument connected to the scale control board than of the one connected to the recorder without the scale control.

An effective semi-automatic recorder has been designed by Mr. H. Brearley for rapidly obtaining recalescent and freezing-point curves. It consists of a moving-coil galvanometer, M, Fig. 15, which is connected to the thermo-couple whose hot junction is within the specimen to be studied. The movements of the galvanometer coil are observed by means of a beam of light reflected from the mirror attached to the coil on to a scale A. A pointer K is made to follow the movements of the beam of light by means of a screw S which the observer rotates by the handle H. (The spot of light has been represented in the figure by means of a piece of paper stuck on the back of the scale.) A pen P is rigidly connected to the pointer, so that the movements of the spot of light are recorded automatically on the clock-work-rotated drum D. An observation of a recalescent point can be made in about ten minutes, assuming that the apparatus is previously erected and standardized.

(To be continued.)

[14] Mr. W. S. Peake originally introduced a more elaborate form of Scale Control Board, in which a Standard Clark Cell automatically corrected for any errors introduced by changes in the temperature of the galvanometer.

[15] "A Thermo-Electric Couple Potentiometer," *The Electrician*, 31st January, 1908. J. A. Harker, "A Direct Reading Potentiometer for Thermo-Electric Work," *Phil. Mag.*, July, 1903. W. P. White, "Potentiometer Installations," *Physical Review*, vol. xxv, No. 5, November, 1907.

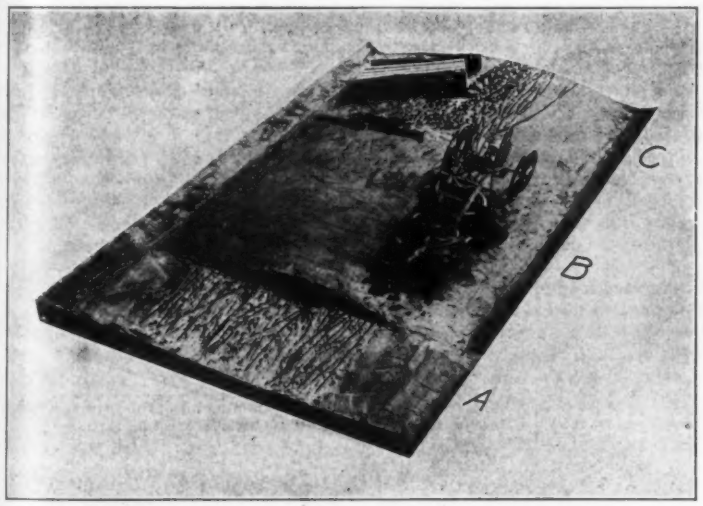

Fig. 1.—Model of earth road, showing split-log drag and grader at work.

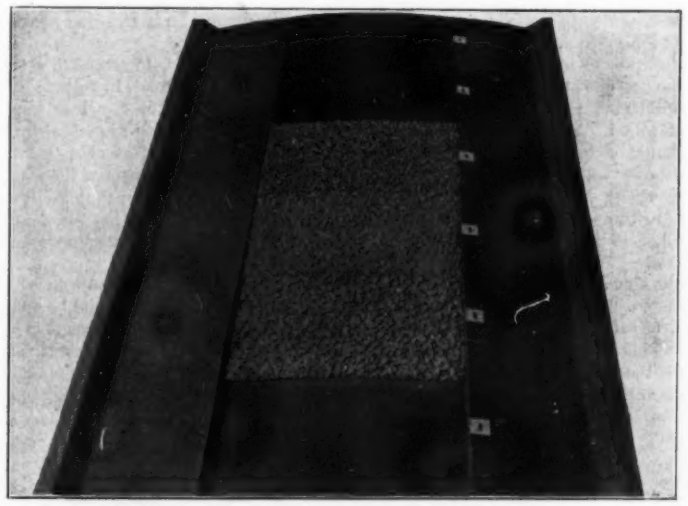

Fig. 2.—Model showing a rock-asphalt Macadam road.

Earth and Sand-Clay Roads*

Road Construction Illustrated by Models

THE mileage of roads in the United States is so vast and the traffic on many of the country roads is so light that it is out of the question to improve more than a small percentage of these roads with a hard surface. This does not mean, however, that all other roads must be neglected. They should be improved just as far as their importance and the traffic will warrant. The common clay roads may be vastly improved by a little judicious grading and systematic maintenance.

In many cases, especially in the vast regions of the South, most of the common roads may be improved, for all practical purposes, merely by the addition of sand or clay, as the case may require, and incorporating this with the surface soil of the road. Thousands of miles of sand-clay roads have already been built in the Southern States at an average cost of about $750 per mile. These roads are almost without exception answering the purpose as well as a far more expensive form of construction would do.

* From Bulletin 47 of the Office of Public Roads, Department of Agriculture.

EARTH ROADS.

Fig. 1 illustrates the construction and maintenance of an earth road. Such roads should be worked when they are damp and soft. The material can then be handled more economically and the resulting road surface will be more satisfactory. After earth roads have once settled down in the spring or summer, they should not be disturbed. If work is then attempted, the material will be brought upon the road in clods, which make only a rough surface when dry and an excess of mud when wet.

Section A shows the old and unimproved roadbed.

Section B illustrates a section of earth road under improvement, together with a road machine or grader. The width of the section shown is equivalent to about 33 feet of finished surface from ditch to ditch.

Section C illustrates an earth road which, though surfaced by a road machine, has rutted under heavy traffic and is being maintained by the split-log drag. In the road illustrated by sections B and C, the crown or slope from the center to the sides is equivalent to 1 inch to the foot.

The surface of section A is characteristic of altogether too many earth roads, in that the center is several inches lower than the sides. This faulty condition makes it impossible for the water to run from the surface; and, even if this were possible, there are no roadside ditches to carry it away. In consequence, the road is usually full of puddles, and cut up with ruts and mudholes.

Section B illustrates the use of a reversible road machine in opening roadside ditches and in shaping the road surface so that it will shed water. The work of this machine is equivalent to the labor of many men, and it is done far better than can be done with shovels and picks. An earth road should have a width of at least 20 feet, or, better still, 24 or 30 feet. If the road is narrow, there is a tendency to use only the narrow central portion, and wagons running in the same rut soon create a water-holding depression. The surface drainage can be provided for by giving the road an average crown or slope from center to sides of 1 inch to the foot. On some soils the crown could be even less than that, but seldom greater. On all earth roads, except sandy sections, side ditches

Fig. 3.—Model of a sand-clay road.

Fig. 4.—Model of a gravel road.

should be built as shown in section B. They can be made and maintained with a road machine, but care should be taken that they have a fall sufficient to carry the water along the side of the road. Through wet and swampy land it is often necessary to raise the roadbed above the general level of the country in order to secure drainage.

For continuous maintenance the split-log drag shown in section C has been devised. This little model has been built to the same scale as the road model—1 inch to the foot. It can be made best from a log 7 or 8 inches in diameter and from 6 to 8 feet long. The log should be carefully split and the halves fastened together with stakes, with the flat sides vertical and facing to the front. The logs, though of the same length, are attached so that the end of the rear log is from 16 to 20 inches nearer the center of the road than the end of the front one. An ordinary trace chain and a set of doubletrees are then attached. When the horses move forward, the drag should slide along the road at an angle of about 45 degrees, with the forward end nearest the ditch, so that it moves the earth toward the road center.

In the construction of this implement care should be taken to make it light enough for one man to be able to lift it. The best material is a dry red-cedar log, though red elm and walnut are excellent, while box elder, soft maple, elm, or willow are superior to oak, hickory, or ash. A broad platform is usually placed on the cross stakes, helping to strengthen the implement and giving a place for the driver to stand. After a little practice a man can learn how best to distribute his weight so as to make the drag cut, spread, and pack the earth properly.

Dragging across the ruts, up one side of the road and down the other, is all that should be undertaken the first time, but this should be repeated after each heavy rain As a mile of road can be dragged in a few hours, the split-log drag provides a simple and inexpensive method of road maintenance. If it is used in conjunction with the road machine, fairly good earth roads can be secured at a nominal expense. Dragging is done for 50 cents per mile in some parts of the country. At this rate, a mile of earth road can be dragged once a month for a year for $6. Some remarkable results have been accomplished with the drag without the aid of the road machine. Farmers' Bulletin 321,[1] "The Use of the Split-log Drag on Earth Roads," deals fully with this subject.

SAND-CLAY ROADS.

Figure 3 illustrates the construction of a sand-clay road 16 feet wide and 8 inches thick when compacted. The crown as shown is 1 inch to the foot.

Section A represents an unimproved sand road about 33 feet wide; section B, an old sand road slightly rounded to receive the clay, and with the center about 4 inches higher than the sides; section C, a portion of road covered with clay to a depth of 6 inches; section D, the harrowing or mixing process; and section E shows the completed road.

The bottom of the ditch of a completed road of this type should be about 16 inches lower than the road at the center, so as to give an average slope of 1 inch to the foot.

As a general rule, sand-clay roads are built on sandy foundations, and it is the usual practice to put the clay on the unimproved foundation, but better results will be obtained if the sandy foundation is given a slight crown. This makes the center from 4 to 6 inches higher than the side ditches. If this is not done, more clay will be necessary to give the road the needed crown, and that is expensive, especially if the material has to be hauled a considerable distance. The process is as follows:

The road is covered with from 4 to 6 inches of clay and worked with a disk or tooth harrow until thoroughly mixed, first dry and finally wet. The final mixing should be done, if possible, during rainy weather. When the mixing has been done, the surface is brought to a crown with the road machine or split-log drag and covered with a thin layer of sand. After two or three rains it may be a smooth, cheap, and satisfactory road suitable for light traffic.

Similar results can be secured by adding sand to a clay road and providing good surface drainage. When building on a clay foundation, it is advisable to plow the clay before adding the sand in order to insure a thorough mixing. Farmers' Bulletin 311,[2] "Sand-clay and Burnt-clay Roads," and Circular 91[2] of the Office of Public Roads, "Sand-clay and Earth Roads in the Middle West," give full information on this subject.

GRAVEL ROADS.

Figure 4 illustrates a properly constructed gravel road 16 feet wide, 6 inches thick at the center and 4 inches thick at the sides when rolled. The crown as shown is three fourths inch to the foot. The road is graded for a width of 33 feet.

[1] Copies of this publication will be sent free to persons applying to the Secretary of Agriculture, Washington, D. C.

[2] Copies of this publication will be sent free to persons applying to the Secretary of Agriculture, Washington, D. C.

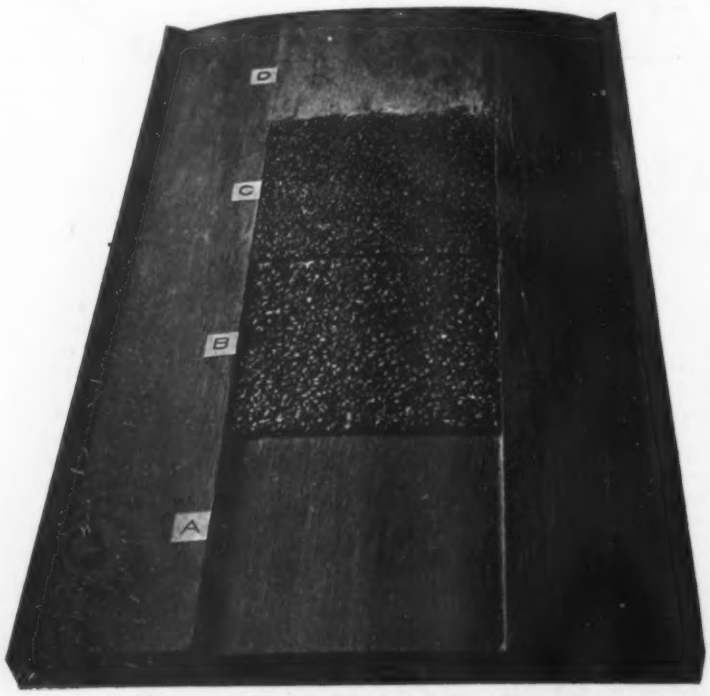

Fig. 5.—Model of a water-bound Macadam road.

Fig. 6.—Model of a bituminous Macadam road—penetration method.

Fig. 7.—Model of a bituminous Macadam road—mixing method.

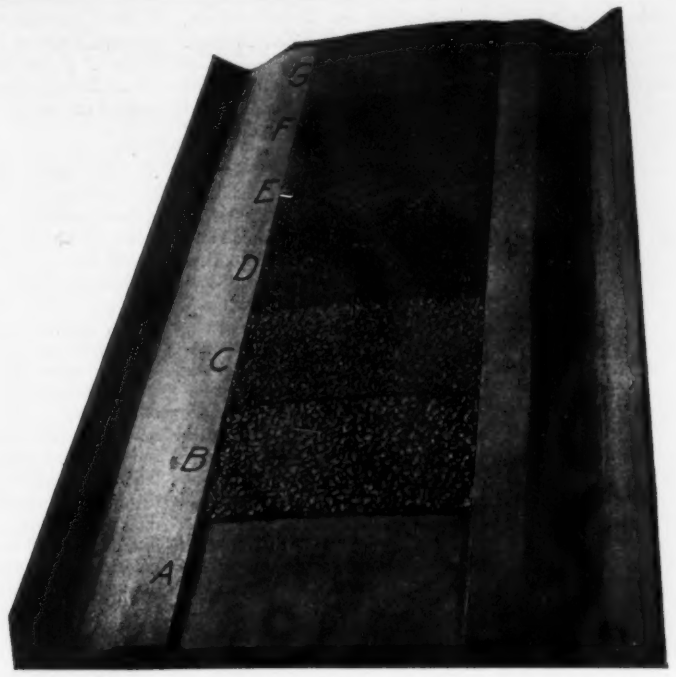

Fig. 8.—Model of a bituminous Macadam road—prepared-filler method.

Section A represents a subgrade or foundation prepared as previously described, with the center about 10 inches higher than the bottom of the side ditches.

Section B shows the first course of gravel, which, after rolling, has a depth of about 4 inches at the center and about 3 inches at the sides.

Section C represents a second course after rolling. There the material is about 2 inches in depth at the center and 1½ inches at the sides. The crown or side slope of this road from center to sides is at the rate of ¾ inch to the foot. In constructing a gravel road the best results will usually be obtained by separating or screening the materials into sizes. For the bottom course material ranging from 1¼ inches to 2½ inches should be used, while for the top course material ranging from 1¼ inches to ¾ inch should be used. The best and cheapest method of screening gravel is by using the rotary screen, with holes 2½, 1¼, and ¾ inch wide. Gravel should contain from 16 to 20 per cent of clay or other binding materials to bond it properly. Roads of this type should be constructed as early in the spring as possible in order to give them time to consolidate thoroughly before the fall and winter rains.

Section C also illustrates how the shoulders shown in the other two sections are finished to correspond with the gravel surface. When plenty of gravel can be obtained cheaply, it will be found more satisfactory to use it for surfacing the whole width of the road than to use it, as above described, with earth shoulders. When it is used in this way, the gravel surface may taper from 6 inches in thickness at the center to 2½ or 3 inches at the edge of the road.

WATER-BOUND MACADAM ROADS.

Figure 5 illustrates the construction of a macadam road 16 feet wide, 6 inches thick at the center and 4 inches thick at the sides when rolled. The crown as shown is five-eighths inch to the foot. The road is graded for a width of 33 feet.

Section A represents the prepared subgrade properly crowned and rolled; section B, the first course of broken stone, 4 inches thick compacted; section C, the second course, 2 inches thick compacted; and section D shows the finished road, an example of which is shown in Figure 6.

In the model the crown or slope of the foundation is about the same as in the finished road, giving an average fall of about three fourths inch to the foot from center to sides. In preparing for the construction of a road of this type it is advisable to roll the foundation thoroughly when the soil is damp, so that all soft spots may be found and filled and that the ground may be prepared firmly and smoothly for the first layer of stone. Shoulders are built on both sides to hold the macadam in place, either by excavation or by piling up the earth shoulders as the work progresses. The shoulders should never be less than 3 or 4 feet wide, and, if possible, they should be 6 or 8. If they are sufficiently wide and have a slope of not more than 1 inch to the foot, they can be used in dry weather for light traffic and thus relieve the macadam of fast travel, which causes it to ravel.

In every case the bottoms of the side ditches should be lower than the road foundation to insure proper drainage. If the road is built of clay or heavy soil, shoulder drains should be built at low places to lead the water from the foundation to the side ditches. These drains are filled with crushed rock or gravel and are covered with soil. The side ditches should be shallow, but wide; their construction is based on the volume of water they may be expected to carry.

The No. 1 crushed rock for the foundation may vary in size from 1½ to 2½ inches in diameter. The depth of this course must depend upon the conditions. If built on light gravelly soil, where little traffic may be looked for, a depth of 3 or 4 inches is sufficient, but for heavy soils and constant traffic the course should be from 4 to 6 inches deep after rolling. For roads 12 feet wide or less the depth of material should be uniform throughout, but if the road is from 14 to 16 feet wide the total depth of both courses may be reduced to 6 inches at the center and 4 inches at the sides.

After the foundation course has been thoroughly rolled the second course, varying in size from three-fourths to 1½ inches, is applied. While rock of inferior quality may be used for the foundation course, nothing but the best hard and tough rock should be used for the surface. It should not only be able to resist the pounding and grinding of traffic, but should have a high cementing value, so that the fine particles will bind the surface into a water-shedding crust. All rolling should start at the side and continue toward the center.

The final course of screenings does not add to the depth of the road, which when completed should be flush with the earth shoulders. The total depth of roads of this type varies from 4 to 12 inches, according to local conditions, but the average depth of such roads in the United States is not more than 6 or 7 inches.

Fig. 9.—Repair and maintenance of Macadam roads—surface treatment.

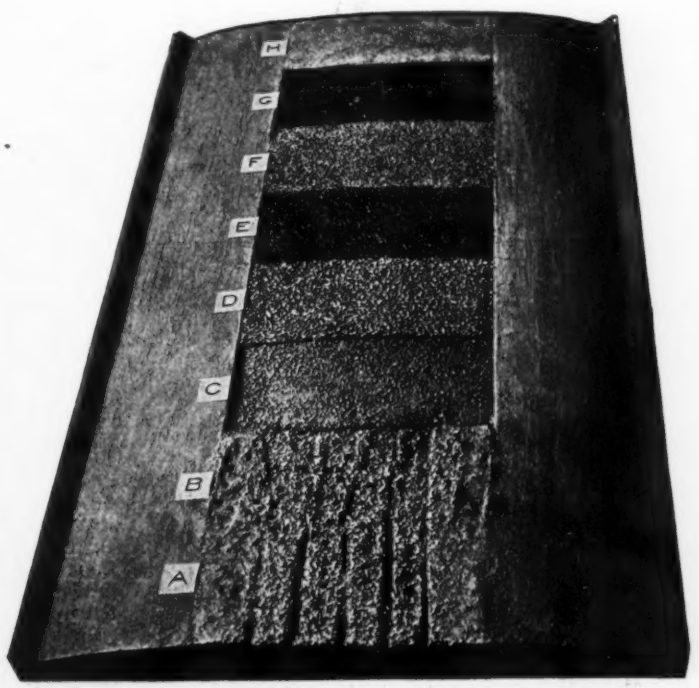

Fig. 10.—Model showing repair of a Macadam road—resurfacing road.

In spreading the surface-bonding course of screenings, the stone may vary from three fourths inch to dust. It is not necessary to separate the dust from the screenings unless the amount of dust is excessive. If too much dust is used the road will be sloppy in wet weather and dusty in dry, while if there is not a sufficient quantity of screenings the road will quickly ravel, especially under fast automobile traffic.

Care and judgment must be exercised in determining the proper amount of screenings and also in spreading them. One thin layer should be spread and rolled and then sprinkled and thoroughly rolled, after which another layer should be spread. By continuing this process until all voids are filled and the surface has been thoroughly consolidated a waterproof surface will be secured.

The importance of road rolling cannot be overestimated. It will be found that in the long run much better and cheaper work can be done with a power roller than with a horse roller, and this type may also be used to advantage in road repair work. If the road surface becomes uneven or rutted, it can be spiked up by teeth placed in the wheels of the roller. Then the surface can be leveled off and resurfaced with another course of No. 2 stone, after which it may be rolled and treated again with screenings. Farmers' Bulletin 338,[1] "Macadam Roads," gives additional information on this subject.

BITUMINOUS MACADAM ROADS.

Since the coming of the automobile, with the consequent aggravation of the dust nuisance, numerous methods have been devised to secure a lasting road surface which would at the same time be within the financial means available for main-line country roads and reasonably free from dust. Probably the most important of these is the group of methods generally classed as bituminous construction.

While these several methods differ greatly as to name and the details of carrying out the work, the fundamental aim of each is the same. This is to secure a smooth, waterproof, and durable surface composed of mineral aggregate, usually broken stone, and bonded in part by the mechanical interlocking of the fragments and more firmly by a bituminous material coating the fragments and filling the interstices. Tars, asphaltic oils, liquid asphalts, tar and asphaltic preparations, and asphalt are the binders more commonly employed.

The usual methods of construction are known as the mixing method, the penetration method, and the filler method. In the mixing method a more or less closely graded aggregate is mixed either by hand or machinery with the proper amount of bituminous binder before placing it on the road. In the penetration method the wearing or second course of stone is laid and rolled as in ordinary macadam; but instead of applying the screenings, hot bitumen is sprinkled or sprayed over the stone in sufficient quantity to coat the fragments and penetrate to a depth of 2 or 3 inches. In the filler method the surface or second course usually is placed in two layers. The first layer is partly rolled and then pea stone or stone chips which have previously been well coated with bitumen are added and the second layer of stone is placed on top of the chips. The pressure of the roller will force a portion of the chips downward in the interstices of the partly rolled stone, while the remainder will work upward, bonding the entire surface course. In some cases the surface course is raked with a tooth harrow in order to mix the chips better with the second course. In each of these forms of construction it is customary to sprinkle a light application of hot bitumen over the surface in order to fill the voids completely and make the surface waterproof. A sufficient quantity of sand, pea gravel, or stone chips is then added to take up any excess of bitumen, the surface is rolled thoroughly, and the road thrown open to traffic.

PENETRATION METHOD.

Figure 6 illustrates the construction of a bituminous macadam road built according to the penetration method.

Section A represents the prepared subgrade 16 feet wide, with the crown one half inch to the foot; section B, the first course of No. 1 stone, 4 inches compacted after rolling; section C, the second course of No. 2 stone, 2 inches compacted after rolling; section D, the application of bitumen at the rate of about 1½ gallons to the square yard; section E, the application of stone chips, after being rolled; section F, a bitumen paint coat applied at the rate of about one half gallon per square yard; and section G shows the completed surface, with clean stone chips lightly rolled, and the crown of the finished road, representing an average fall of about one half inch to the foot.

The construction of this road, through the application of the No. 1 and No. 2 courses, is the same as an ordinary macadam road. It varies from the method of construction of a macadam road in that hot tar or asphalt is flushed into the No. 2 course before the screenings are applied.

[1] Copies of this publication will be sent free to persons applying to the Secretary of Agriculture, Washington, D. C.

After the application of hot tar or asphalt a light coat of clean stone chips is spread and rolled lightly into the surface. Following this process a paint coat of hot tar or asphalt is applied and another layer of screenings spread and rolled into the surface.

MIXING METHOD.

Figure 7 illustrates the construction of a tar, oil, or asphalt macadam road, built according to the plan ordinarily referred to as the "mixing method."

Section A illustrates the prepared subgrade 16 feet wide, with the crown one half inch to the foot; section B, the first course of No. 1 stone compacted to a depth of about 4 inches; section C, the second course of bitumen-covered stone spread to a depth of about 2 inches when compacted; section D, the application of a layer, about one fourth inch thick, of bitumen-covered sand or stone chips, which, after being rolled firmly into the surface voids, should add nothing to the thickness of the road; and section E shows the completed surface and the clean chips or sand lightly rolled, leaving the road with a sloping crown of about one half inch to the foot. The course of bitumen-covered stone is prepared by applying sufficient hot bitumen to cover a graded mineral aggregate when mixed. This graded aggregate is composed of No. 2 stone and stone ranging in size from three fourths inch to dust in proportions of 960 pounds to 350 pounds.

Before applying the bitumen-covered sand this course must be thoroughly rolled and the sand then applied in such quantities that it will fill the surface voids and bring the surface to a smooth and even condition. The final coat of stone dust is applied merely for the purpose of taking up any excess of bitumen and of giving the road a pleasing appearance.

PREPARED-FILLER METHOD.

Figure 8 shows the construction of a bituminous macadam road built according to the prepared-filler method.

Section A represents the prepared subgrade, which has a crown of three fourths inch to the foot and is well rolled.

Section B shows the first course of No. 1 broken stone. The stone varies in size from 1¼ to 3 inches and is placed to a depth of about 5½ inches loose or 4 inches rolled.

Section C represents the second layer of broken stone. The size of the stone in this layer varies from three fourths inch to 1¼ inches. The stone is spread to a depth of about 3 inches loose or 2½ inches rolled.

Section D illustrates the application of the bituminous prepared filler, spread to a depth of about 1½ inches. The filler is made up as follows: Stone chips from one eighth to three fourths inch, sand, and from 7 to 12 per cent bitumen, each heated separately and mixed. The mixture is applied hot.

Section E represents the mixing of the prepared filler with the No. 2 stone, by means of harrowing. The harrowing is continued until the No. 2 stone appears in the surface, after which the filler is thoroughly rolled with a steam roller.

Section F represents the second layer of filler, which is spread to a depth of about one half inch and thoroughly rolled.

Section G shows the application of a light covering of screenings to take up the surplus bitumen, after which a thorough rolling completes the road.

ROCK-ASPHALT MACADAM ROADS.

Figure 2 represents a rock-asphalt macadam road surfaced to a width of 16 feet. The macadam is compacted to a total depth of 8½ inches and the crown is made one half inch to the foot. The rock asphalt is spread on the road at the rate of 80 pounds to the square yard.

Section A represents the prepared subgrade; section B, the first course of stone, ranging in size from 2 to 3 inches, with a depth of 3 inches when compacted; section C, the second course of stone, ranging in size from 2 to 3 inches, filled with stone chips or sand and having a depth of 3 inches when compacted; section D, the third course of stone, ranging in size from 1½ to 2½ inches, with a depth of 2½ inches when compacted; section E, the rock asphalt, to the extent of 40 pounds per square yard, or about three fourths inch loose, rolled in to fill the voids; and section F shows the finished surface, composed of rock asphalt, spread at the rate of 40 pounds per square yard, which is equivalent to a course about three fourths inch thick before rolling.

MAINTENANCE OF MACADAM ROADS.

Surface Treatment.

The surface treatment of an old macadam road with tar or oil is shown in Figure 9.

Section A shows a disintegrated macadam surface; section B, the surface after sweeping; section C, the application of oil or hot tar at the rate of about one-half gallon per square yard; and section D, the application of sand to the oiled surface, completing the treatment.

Before any application of oil or tar is made all loose material should be removed and the road surface should be absolutely dry. In applying tar or oil a number of methods may be adopted. It may be poured by hand, or by means of a sprinkling wagon. The liquid should be thoroughly broomed into the oil surface before the sand is applied, in order to secure perfect cohesion. Enough sand should then be applied to take up any excess of tar or oil that may be left on the surface.

RESURFACING MACADAM ROADS.

Fig. 10 illustrates the restoration of a macadam road to its original condition after it has become badly worn. The macadam width as shown is 16 feet, and the crown is one half inch to the foot.

Section A represents the worn macadam surface; section B, the surface after spiking; section C, the road after it has been recrowned; section D, the application of 2 inches of new stone, compacted after rolling; section E, the application of tar or asphalt by the penetration method at the rate of about 1½ gallons per square yard; section F, the application of stone chips after being rolled; section G, a tar paint coat averaging about one half gallon per square yard; and section H, the finished surface.

This model illustrates the usual custom of restoring a macadam road which has become badly worn and rutted owing to excessive travel and lack of maintenance. It shows that unless roads are given proper maintenance at the proper time it will become necessary to make extensive repairs at some time in the future.

The Aerial Gulf Stream

THE Gulf Stream, when it leaves the Gulf of Mexico, enters the Atlantic with a speed of 8 kilometers an hour. It is 60 kilometers wide and 400 meters deep, and daily transports about 40 millions of milliards of calories. This enormous quantity of heat, of which it is almost impossible to obtain an exact idea, plays a fundamental rôle in the general climatology of the earth. Strangely enough it is this stream of hot water, exercising its temperature action on the coasts it waters, which is the direct cause of the existence of deserts. And this is how. Water is one of the bodies in which heat is the most easily preserved, and consequently the Gulf Stream, even in high latitudes, still keeps an enormous quantity of heat. The masses of air that rest on these hot waters are kept at a temperature higher than the surrounding temperature and form a veritable aerial gulf stream superposed over the marine current. But the aerial current is not like the marine one arrested by the mass of the continents. It continues its route above Europe, abandoning, in the form of rain, the enormous masses of water it contains; it is these abundant precipitations which feed the numerous lakes of Sweden, Finland, and Northern Russia. But, on account of the rotation of the earth, the aerial current turns first to the east, then inclines toward the south. It thus constitutes masses of dry cold air which give to the plains of Russia their principal meteorological character. As it draws nearer to the Equator the current is again warmed, but remains at the same time dry and without vapor; its direction is then northeast, and it is in the state of a drying wind that it blows over the regions it crosses. It is the origin of the band of deserts of Turkestan, Arabia, Sahara, which are to be found on its return route. After having left the Continent, the aerial current, thanks to the trade-winds, links itself on again to its starting point, the Gulf Stream, thus looping its circuit after having, like everything else, done much good and much evil.—*Chemical News.*

Etching on Brass and Steel

FOR etching on brass a satisfactory ground can be made from equal parts of beeswax, Burgundy pitch and asphaltum. These constituents are melted together and thoroughly stirred in order to secure a uniform mixture. This ground is warmed before using and spread evenly over the surface that is to be etched. After the ground has had time to cool, it is removed from those sections of the metal that are to be etched, after which the etching fluid is applied. A satisfactory etching fluid consists of one part of nitric acid to four parts of water. After the "biting" has been completed, which takes only a few minutes, the work is dipped in hot water to wash off the acid. The surface of the work can then be cleaned by wiping it with a cloth dipped in benzine or gasoline.

For etching steel the ground is also made of equal parts of beeswax, Burgundy pitch and asphaltum. This ground is applied to the work according to the instructions given for application on brass pieces. The etching solution used for steel consists of:

Pyroligneous acid	4 ounces
Alcohol	1 ounce
Nitric acid	1 ounce

As soon as the biting operation is completed the work is dipped in hot water to wash off the biting solution, after which the work is cleaned with gasoline or benzine, as in the case of etching operations on brass. In order to obtain satisfactory results it is important to have the work perfectly clean before the ground is applied.—*Machinery.*

Industrial Research in America—II*

What Our Government is Doing for the Advancement of Science

Continued from SCIENTIFIC AMERICAN SUPPLEMENT No. 1974, Page 282, November 1, 1913

ANY attempt to adequately present the enormous volume of research work, much of which is of the highest grade, constantly in progress in the many scientific bureaus and special laboratories of the general government or even to indicate its actual extent and range, is of course utterly beyond the limits of my attainments or of your patience. The generous policy of the Government toward research is unique in this, that the results are immediately made available to the whole people. Heavy as some of the Government reports are, they cannot be expected to weigh more than the men who write them. Some, like the Geochemistry of F. W. Clarke are of monumental character. A vast number are monographs embodying real and important contributions to scientific knowledge or industrial practice. Some, as would be expected, are little more than compilations or present the results of trivial or ill-considered research.

The United States is still essentially an agricultural country and agriculture is, in its ultimate terms, applied photo-chemistry. The value of our farm property is already over $42,000,000,000, and each sunrise sees an added increment of millions. Even small advances in agricultural practice bring enormous monetary returns. The greatest problem before the country is that of developing rural life.

Chief, therefore, among the Government Departments, in the volume of industrial research is of course the Department of Agriculture, which includes within its organization ten great scientific bureaus, each inspired by an intense pragmatism and aggressively prosecuting research in its allotted field. The magnitude of these operations of the department may be inferred from the fact that it spent for printing alone during the fiscal year just ended $490,000. The activities of its army of agents literally cover the earth, and its annual expenditure runs to many millions. The Bureau of Soils, the Bureau of Plant Industry, the Bureau of Animal Industry and the Forest Service have to do with the very foundations of our national existence and prosperity, and their researches have added billions to the national wealth. The Bureau of Chemistry, through its relation to the enforcement of the Pure Food Law and the inspection of meats before interstate shipment, is as ubiquitous in its influence as the morning newspaper and touches the daily life of the people almost as closely. The consumer is by no means the only one benefited by its activities. Manufacturers are protected from the unfair competition of less scrupulous producers. The progress of research is stimulated not only by investigations within the Bureau, but by their reaction upon the manufacturers of food products who are rapidly being brought to establish laboratories of their own. The food work of the Bureau is supplemented and extended by the laboratories of the State and city Boards of Health, of which that of Massachusetts has been notable for productive research. Special laboratories within the Bureau carry its influence and investigations into other fields as in case of the Paper and Leather Laboratory.

The Office of Public Roads of the Department, mindful of the fact that less than ten per cent of the total road mileage of the country has ever been improved, maintains a large organization of engineers, chemists and other scientists to conduct investigations and compile data, the ultimate purpose of which is to secure efficiency and economy in the location, construction and maintenance of country roads, highways and bridges.

The research work of the Department of Agriculture is greatly augmented and given local application through the agency of 64 State agricultural experiment stations established for the scientific investigation of problems relating to agriculture. These stations are supported in part by Federal grants, as from the Hatch and Adams funds, and for the rest by State appropriations. Their present income exceeds $3,000,000. All are well equipped; one, California, includes within its plant a Station of 5,400 acres with buildings worth $1,000,000.

The station work is organized upon a national basis but deals primarily with the problems of the individual states. The efficiency of their work is stimulated by the requirement of the Adams Fund that appropriations shall be confined to definite projects. The number of such projects during 1910 was 335 and during 1911, 290. The reduction in number in no way implies diminished activity, and is due to more careful selection and preparation, with eliminaton of trivial and merely demonstrational projects. While the work of the stations necessarily covers a wide range of subjects, many of which would not be regarded as chemical in nature, a notable porportion has to do directly with chemical projects. Only the briefest reference can be made to a few of these.

In Connecticut, Osborne's studies of proteins and their feeding values have developed differences as great as in their assimilability as those existing between the different carbohydrates.

Kansas has a department for the study of problems in handling and milling grain with an experimental baking plant for testing the bread making capacity of flours. The millers are actively cooperating.

Minnesota has a similar thoroughly modern baking and testing laboratory for studies in wheat and flour chemistry and technology.

Arizona finds that date ripening may be so hastened by spraying the immature fruit with acetic acid that choice varieties are caused to ripen in that region.

The Cornell Station has demonstrated that the growth of a legume with a non-legume gives the latter a greater protein content than when grown alone.

Wisconsin has established the significance of sulphur as a plant-food; grain crops for example remove nearly as much sulphur as they do of posphoric acid, whereas the soil supply of sulphur is far less.

Vermont is studying the forcing of plants by means of carbonic acid gas.

Idaho has raised the protein content of wheat by 50 per cent. Kentucky has developed a method for the detection of Bacillus typhoeus in water, and North Dakota is conducting very extensive field tests on the durability of paints and oils.

No other organic substance occurs in such abundance as wood and few if any are more generally useful. About 150,000,000 tons of wood are still wasted annually in the United States. The Forest Products Laboratory which is maintained by the Forest Service in Cooperation with the University of Wisconsin has for its purpose the development and promulgation of methods for securing a better utilization of the forest and its products and its research work is directed to that end. The laboratory is splendidly equipped with apparatus of semi-commercial size for work in timber physics, timber tests, wood preservation, wood pulp and paper and wood distillation and chemistry.

In the United States Patent Office Dr. Hall has developed a remarkably comprehensive index to chemical literature which now contains 1,250,000 cards and which is open to every worker. The Bureau of Fisheries devotes $40,000 to a single study and the Geological Survey $100,000 to the investigation of the mineral resources of Alaska. It spent in 1913 $175,000 for engraving and printing alone. The superb Geophysical Laboratory of the Carnegie Institution of Washington is also constantly engaged in the most refined researches into the composition, properties and mode of genesis of the earth's crust. The Smithsonian Institution is honored throughout the world for the efficiency of its effort to increase and diffuse useful knowledge among men.

The Bureau of Mines of the Department of the Interior has established to conduct in behalf of the public welfare fundamental inquiries and investigations into the mining, metallurgical and mineral industries. Its appropriation for the current fiscal year is $662,000, of which $347,000 is to be devoted to technical research pertinent to the mining industry. The Bureau has revolutionized the use of explosives in mines. Over $8,000,000 of coal is now bought on the specification and advice of the Bureau while more than 50 of the larger cities, a number of States, and many corporations have adopted the Bureau plan of purchase. Our own Dr. Parsons, as chief mineral chemist of the Bureau, is carrying its researches into new and interesting fields.

Perhaps no better evidence could be adduced of the present range and volume of industrial research in America than the necessity, imposed upon the author of such a general survey as I am attempting, of condensing within a paragraph his reference to the Bureau of Standards of the Department of Commerce. Its purpose is the investigation and testing of standard and measuring instruments and the determination of physical constants and the properties of materials. To these objects it devotes about $700,000 a year to such good effect that in equipment and in the high quality and output of its work it has in ten years taken rank with the foremost scientific institutions in the world for the promotion of industrial research and the development and standardization of the instruments, materials and methods therein employed. Its influence upon American research and industry is already profound and rapidly extending. The Bureau co-operates with foreign governments and institutions, and is constantly consulted by State, municipal officials, technical bodies and commissions as a court of highest appeal.

(To be continued.)

*Extract from the presidential address before the American Chemical Society.

Fuel Consumption in Motor Ships*

As a number of motor-ships have now been in extensive operation for some considerable time, it is possible to arrive at the exact figures relating to the fuel consumptions which have been obtained in practice, and these are of interest not only from their relation to coal consumption on steamships, but also in reference to their deviation from the results which have been obtained in shop tests.

DIFFICULTIES OF COMPARISON.

Probably too much has been made, generally among interested parties, of the differences which have been exhibited by different types of engines, and in particular by the four-cycle type, on the one hand, and the two-cycle motor on the other. It is only by a careful examination of the various methods of operation of Diesel engines that it becomes evident that in many cases the consumption given are quite dissimilar and do not permit of direct comparison. For instance, it is quite common, in fact almost general, to give these results in the form of fuel consumption in lb. per brake horse-power hour without any special reference to the method of driving the auxiliaries which are necessary in connection with every Diesel engine installation.

In some motors the air-compressor is driven direct off the engine, but in others it is entirely separate, while in a third type one stage of the air-compressor is driven off the main motor, and the low-pressure and intermediate pressure stages are themselves separately operated by an auxiliary Diesel engine. Under these conditions, therefore, it is obvious that to obtain a fair comparison between the many types of engines is by no means easy, and particularly is this the case when comparisons are made also with two-cycle motors and four-cycle engines. While, however, in all the existing two-cycle engines which have yet been put in service on ships the scavenging pumps are driven direct off the engine, it is certain that in the larger types, or at any rate in some of them, those pumps will be quite separate and so again complicate the actual fuel consumption per brake horse-power hour.

It might be thought, in view of these difficulties, that it would be advisable to calculate the consumption based on the indicated horse-power of the engine; but here again the difficulty arises of the different mechanical efficiencies of the various types of motors. Possibly where it is desired only to arrive at scientific comparisons between different engines, this method might be advocated, but after all, since such a matter is more or less a commercial one, it is essential for the users themselves to know what the consumption of an engine is in terms of the actual useful power developed by that engine.

THE FIGURES RECORDED.

After a thorough examination of the various results which have obtained, and taking into consideration all the various factors which influence the problem, it is now possible to state fairly definitely that—speaking in a general manner so as to include practically every type of marine oil-engine which has been put into service—the fuel consumption per brake horse-power hour is always between 0.4 lb. and 0.46 lb. In view of the varying circumstances which arise in actual service, it is not too much to say that the range of difference is much less than has been anticipated and to a large extent is negligible when the variations between these figures and the corresponding consumption of steamships are considered. It seems that the difference between two-cycle and four-cycle engines in fuel consumption is not so great as to be an absolutely deciding factor in the development of the two designs. Probably it varies between 5 and 10 per cent, being, of course, in favor of the four-cycle motor.

The figures given above for the fuel consumption may be taken in the case of ordinary cargo vessels or tank boats to include the necessary fuel for the operation of the few auxiliaries which have to be working while the ship is at sea. In certain instances a figure so low as

*Reproduced from the Engineering Supplement of the London *Times*.

0.39 lb. per b. h. p. has been obtained for the engine alone, but this is somewhat exceptional and applies only to four-cycle engines.

It will be seen, therefore, that the anticipation with regard to the fuel consumption of oil-engines of the Diesel type has been borne out in practice, and that the fear expressed by many that the shop tests would not form a true criterion of actual fuel consumption at sea has not been justified.

POSSIBILITY OF DECREASED CONSUMPTION.

On the other hand, it seems unlikely that there will be any considerable decrease in fuel consumption as the development of the Diesel engine continues, since it is not in any question of principle that improvements will be made, but rather in constructional details which will facilitate operation and increase the reliability without adding to the efficiency of the engine as a marine motor. This is somewhat in contradistinction to the development of the steam-engine, which as time has progressed has become a much more efficient machine that it was when it was originally produced for marine work. There is nothing in a Diesel installation corresponding to such improvements as the adoption of condensers, the use of superheated steam, the employment of feed water heaters, and similar details, all of which have added considerably to the efficiency of steam-engines. A better fuel consumption with internal combustion engines appears probable only in the event of an entirely new heat cycle being developed, of which at present there is no indication. Even as the sizes of marine oil-engines increase, there will not be a very large reduction in specific fuel consumption, as is the case with steam-engines and steam-turbines, and this is already noticeable in the motor-ships which have already been built. For instance, in a vessel which has an engine of only 500 horse-power, the consumption per brake horse-power hour is but slightly different from one in which the total power is 2,500 horse-power. Even when the very large Diesel engine for battleships develops power up to 12,000 and 15,000 horse-power it is not likely that the fuel consumption per brake horse-power hour will drop much below the figures of the small motors.

Dodges With Lenses and Tripod Stands

THE lens, perhaps (writes "Practicus," in the course of an excellent series of articles on "Improvising Apparatus," in the *British Journal of Photography*), appears the most unlikely instrument to deal with in the way of dodging; but if the user dares to discount the statements of the optical pundits, he will find that quite a lot can be done in the way of getting work out of a lens in a way never contemplated by the original designer. Putting aside the pinhole *per se*, which everybody knows all about, the pinhole plus lens is worthy of some attention. The scientific opticians tell you that when the aperture of a lens is reduced to less than F171, diffraction ensues, with consequent loss of definition. This is probably true; but the loss of definition is not such that it can be detected in an ordinary negative, especially if a matt paper be used for printing. If, therefore, we defy the diffraction bogey, we can add to the powers of our lenses by making a pinhole-stop of black paper, which is put in contact with the iris. This simple contrivance gives such an enormous amount of depth of focus that a 7-inch lens may be made to give a fairly sharp image at any camera-extension between 5½ inches and 8½ inches, the view-angles being approximately equal to those included by lenses of these focal lengths. It is obvious that this device can be worked only upon well-lighted subjects; but, given these, it is of great value. Let us suppose that we have to photograph a building from a position which is just too near to allow the whole subject to be included on the plate. All that has to be done is to stop the lens down to the smallest aperture, rack in the bellows until the image appears of the desired dimensions, and insert the pinhole-stop. The same effect can be obtained by temporarily fixing one of the combinations of a larger lens in front of the ordinary lens, and using a small stop. If this be done, accurate centering is not necessary. I have even fastened the supplementary lens in position with strips of rubber plaster. To increase the focal length, the front lens of the ordinary lens may be removed, and the supplementary lens fixed in front of the tube. This method is, of course, only applicable when the shutter is between or behind the lenses. With lenses fitted with Waterhouse diaphragms, it is quite easy to make a stop of brown paper if you have the misfortune to come out without one. One ingenious individual even dispensed with the paper, and cut his diaphragm out of a green leaf. A small iso-screen may often be used upon a large lens by putting it in contact with the diaphragm. I have used a 1-inch screen on a 24-inch rapid rectilinear by actually nipping it in the iris and letting the brass cell serve as the diaphragm.

A tripod-stand of any practical value cannot readily be improvised, although a fair one may be made in an hour with three broomsticks and a piece of ¾-inch wood, so that it is better to press any convenient substitutes into service. A pair of household steps is useful for small cameras, as these may be placed on any of the treads which happen to be at a convenient height. Three ordinary cane-seated chairs form an excellent camera-stand. The first is stood in its normal position, the second is inverted upon it, and the third stood the right way up, with the cross-rails resting on those of the inverted legs. I have used such a stand successfully with a 12 by 10 camera. In many difficult positions, such as upon scaffolds and about unfinished buildings, a light plank, with a hole near one end to take the tripod-screw, will often enable the camera to be fixed in an otherwise impossible position. As an instance, I may say that I had once to photograph a garden from a high window which was at right angles to the desired direction. The camera was fixed on its plank, with the lens pointing to the side, run out of window, and the image arranged on the screen by means of a mirror. If a painter's "cripple" had been available, I should, of course, have preferred to use it. A "cripple" fixed on a ladder makes an excellent camera support, as it may be set to any height. It is always advisable to carry a very long tripod-screw fitted with a fly-nut, so that the camera can be attached to a board of any reasonable thickness. Nearly all cameras are now fitted with the ¼-inch Whitworth bush, and suitable screws may be got for a few cents in a hardware store. If your camera has an odd-sized bush, have it altered. If you have lost or forgotten the screw, and there is no shop near, cut a piece of wood, and taper the end just to enter the bush. It will cut a sufficiently good thread to hold the camera if handled gently.

The Aerial Propulsion of Barges

THE proceedings in the Engineering section of the recent meeting of the British Association for the Advancement of Science opened with a paper by Mr. F. W. Lanchester on "The Internal Combustion Engine as applied to Railway Locomotion." The author of the paper remarked that the steam locomotive, having survived for nearly a century, with all its essential features unchanged, appeared to be about to yield supremacy to other methods of traction. At the present time development was taking place along two distinct lines—(*a*) by the complete electrification of the system, in which case the prime mover was stationary, and the power was transmitted to the locomotive mechanism electrically; and (*b*) the substitution of the internal combustion engine for the steam engine and boiler. The development in the latter direction took two forms—one in which the internal combustion engine was virtually the portable power station, and was employed to generate current which, in turn, drove the electric motors connected with the axles; and the other the method in which the power was transmitted, mechanically, to the axles, as in an ordinary motor vehicle. There was also a system which might be said to lie halfway between the portable electric installation and the motor-car type—a mixed gasoline-electric. One of the problems to be faced in applying the internal combusion engine was how to provide for the additional tractive effort in emergency conditions. A decision had to be made as to the most suitable method of application of the system to the needs the of railway work. Mr. Lanchester went on to describe latest development in the form of the gasoline coach, and expressed the hope that in the future it would be possible that independent coaches could be coupled up to form trams under the control of the leading coach, and be uncoupled to form independent sections at various junctions on the line. The gasoline coach was capable of running at the rate of seventy miles an hour.

Visualizing Plato

THE Physiology Section and the Sub-Section for Psychology of the British Association for the Advancement of Science met together at Birmingham. In the first paper read, Prof. R. Ogden described experiments made in the localization of visual images. He said the primary aim of the experiments was to secure visual images suggested by a series of fifty words exposed in a card-changer. Above the word was pasted a round disk of "granite" paper, two centimeters in diameter, which the observer was instructed to fixate. As soon as an image appeared the subject reacted, and then described the nature of the image which had occurred. There were six observers; two of them, however, performed but half the series. Thus there were 250 experiments in all, which produced 251 images. At times no image was reported, and at times two or three occurred in one experiment. Of the 251 images 138 were reported as memory, 75 as imaginary, while 38 were equivocal. The images were all projected except in five instances for one observer, who described these as being "in his head." One observer placed all images upon the fixated disk. Another placed none there. The other four placed their images both on and off the disk. The correlation of the localization with the nature of the image as memory or imaginary furnished some interesting results. The images of memory tended to be located at their proper place and distance, and the images of imagination tended strongly to be placed upon the disk. Those observers who placed few or no images upon the disk tended to locate images of imagination in the near-by space. For all who located their images variously there was a marked tendency to project the images of memory into the distance, and the images of imagination at or near the disk. In many instances there occurred a strong tendency to locate the image upon the disk irrespective of its nature as a memory or imaginary product. In such cases a marked inertia of the image was manifest. This applied to both classes of image; both resisted attempts to move them from their original location. This was especially marked in the attempts to remove memory images from a distant location to the disk.

In reply to questions, Prof. Ogden said some of the words used were purse, diver, bed, hammer, pencil, Taft, viaduct, and dean. In the case of the word "Plato" the observer described what he saw as a "tall man bald in front of the head, dignified broad face and forehead, wearing a black suit and long coat—(laughter)—looked as if he were on the stage or "up" somewhere—(laughter)—looked as though he were thinking.

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